IRENA

International Renewable Energy Agency

WORLD ENERGY TRANSITIONS OUTLOOK 2023

1.5°C PATHWAY

PREVIEW

IRENA
International Renewable Energy Agency

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The data presented herein is accurate at the time of publication. Modelling results may change ahead of the launch of the full report.

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.

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WORLD ENERGY TRANSITIONS OUTLOOK 2023

PREVIEW

MESSAGE FROM THE DIRECTOR-GENERAL

The recent Synthesis Report of the IPCC Sixth Assessment has delivered a sobering message - one that leaves little ambiguity as to the need for immediate action. 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. Within this timeframe, the only realistic option available is a considerable scale-up of renewable energy and efficiency solutions.

The International Renewable Energy Agency's 1.5°C pathway positions electrification and efficiency as key transition drivers, enabled by renewable energy, clean hydrogen and sustainable biomass. This preview of the *World Energy Transitions Outlook* provides an overview of the progress achieved in developing and implementing these technological avenues. It shows that the scale and extent of the change achieved in all sectors to date fall far short of what is required to stay on the 1.5°C pathway. Most of the progress so far has been made in the power sector, where advances in technology, policy and innovation have taken us a long way.

Current energy structures were designed to support fossil fuels and must be re-designed to support renewable energy systems. The emphasis must shift from supply to demand, toward overcoming the structural obstacles that impede progress. This preview outlines three priority pillars - *physical infrastructure; policy and regulatory enablers;* and *a well-skilled workforce* - that must be addressed simultaneously, requiring significant investment and a new paradigm for international co-operation in which all actors can engage in the transition and play an optimal role.

There is no time for a new energy system to evolve gradually over more than a century - as was the case for the fossil fuel-based system. We simply cannot continue with incremental changes if we are to achieve the necessary reductions in carbon emissions to meet climate goals. The Global Stocktake concluding at COP28 in the United Arab Emirates presents the opportunity to assess requirements and determine the best path to rapid, lasting change. To this end, the forthcoming *World Energy Transitions Outlook* will provide a comprehensive assessment of the energy transition and propose effective ways to accelerate progress following this important climate action milestone.

Francesco La Camera
Director-General, IRENA

KEY MESSAGES

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 on natural systems, human societies and economies. Achieving the necessary course-correction in the energy transition will require bold, transformative measures that reflect the urgency of the present situation.

Current pledges and plans fall well short of IRENA's 1.5°C pathway and will result in an emissions gap of 16 gigatonnes (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 carbon dioxide (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,[1] the emissions gap is projected to reach 35 Gt by 2050, underscoring the urgent need for comprehensive action to accelerate the transition.[2]

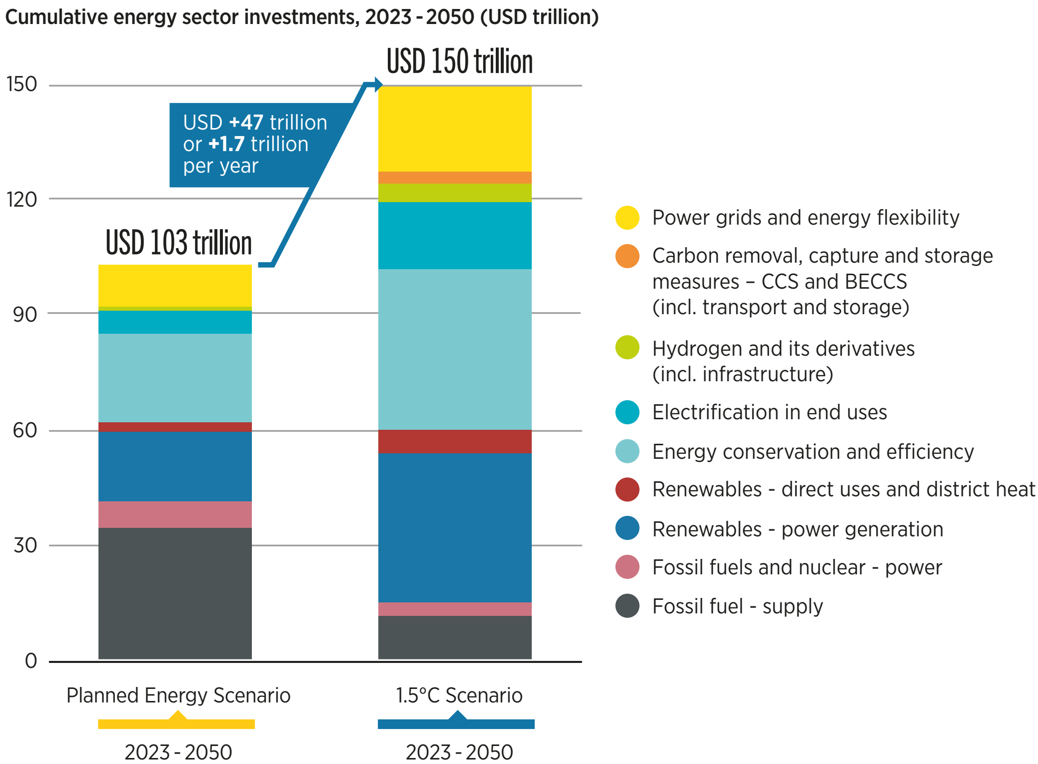
Although global investment across all energy transition technologies reached a record high of USD 1.3 trillion in 2022, annual investment must more than quadruple to remain on the 1.5°C pathway. A cumulative USD 150 trillion is required to realise the 1.5°C target by 2050 (Figure 1), averaging over USD 5 trillion in annual terms. 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.

Cumulative investments between now and 2030 need to total USD 44 trillion, with energy transition technologies representing 80% of the investment, or USD 35 trillion. Total cumulative energy sector investments in the Planned Energy Scenario until 2030 are USD 29 trillion. An additional cumulative investment of USD 15 trillion - or an annual average investment of USD 1.9 trillion - would be needed in the 1.5°C Scenario until 2030. Furthermore, a change in the volume and type of investments is required under the 1.5°C Scenario to prioritise the energy transition and set the stage for a dramatic decrease in the fossil fuel share by 2050 (Figure 1).

[1] *For a brief overview of the two scenarios employed in the World Energy Transitions Outlook, see inside rear cover, page 23.*

[2] *The present IRENA scenarios include CO_2 emissions from fossil fuel combustion, waste incineration and industrial processes. COP announcements reflected in Nationally Determined Contributions [NDCs] as of 5 November 2022, long-term low greenhouse gas emission development strategies [LT-LEDs] and net-zero targets as of 5 October 2022 also include land-use emissions.*

FIGURE 1 **Total investment by technological avenue from 2023 to 2050 for achieving the 1.5°C Scenario**



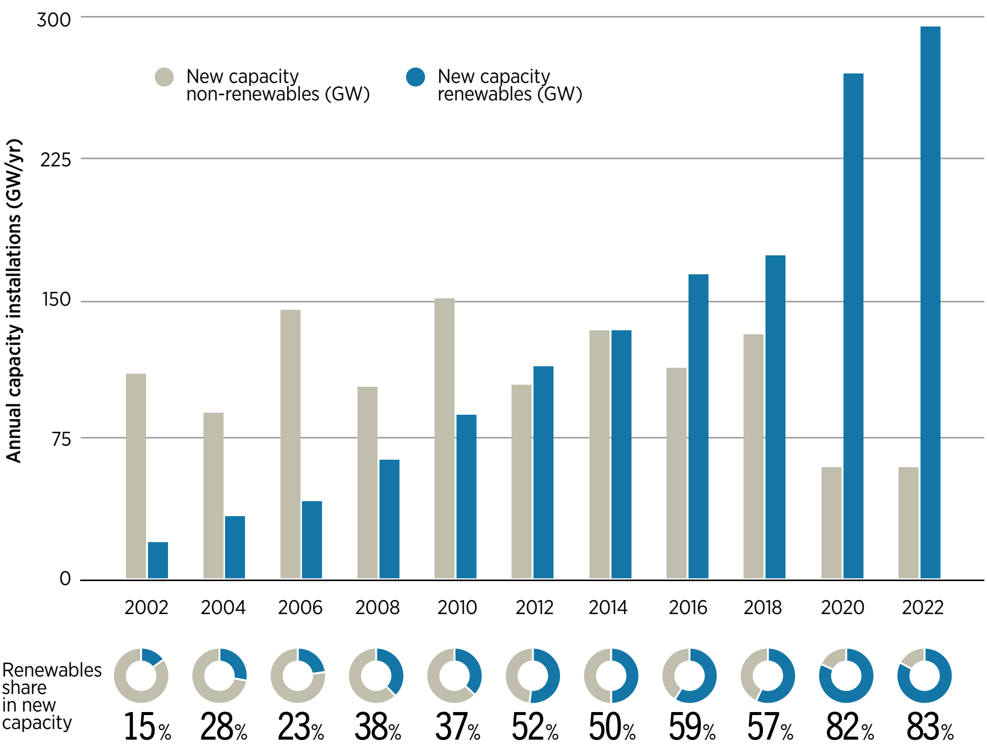
Notes: CCS = carbon capture and storage; BECCS = bioenergy, carbon capture and storage.

Annual investments across all energy transition technologies must more than quadruple to remain on the 1.5°C pathway.

Existing renewable power targets would increase total renewable power capacity to 5.4 terawatts (TW) by 2030, representing less than half of the 11.2 TW needed for a 1.5°C pathway. There is significant scope for aligning and strengthening targets in the short term to provide policy clarity and certainty. In many cases, targets in national energy plans are yet to be aligned with those in NDCs. In addition, targets should be measurable and cover end uses beyond power. Of the 183 Parties with renewable energy components in their NDCs, only 143 had a quantified target - 108 for power and 31 for heating and cooling, transport or cooking (IRENA, 2022).

Some progress is being made, notably in the power sector, with renewables representing 83% of capacity additions and reaching 40% of installed power generation globally in 2022. A total of 295 gigawatts (GW) of renewables was added worldwide in 2022, the largest-ever annual increase in renewable energy capacity (IRENA, 2023a). The strong business case for renewables, coupled with supportive enabling policies, has sustained an upward trend in their share of the global energy mix. However, overall deployment remains centred on a limited number of counties and regions, with China, the European Union and the United States accounting for 75% of capacity additions. Although large-scale deployments of renewable energy are typically associated with countries that have well-developed power systems, it is essential to expand deployment elsewhere, especially in developing nations that lack access to electricity.

FIGURE 2 **Annual power capacity expansion, 2002-2022**



More investments need to flow into developing and emerging markets to make the energy transition more inclusive.

Renewable energy investment remains concentrated in a limited number of countries and focused on only a few technologies. Investment in renewables reached USD 0.5 trillion in 2022; however, this is less than one-third of the average investment needed each year in renewables under the 1.5°C Scenario. Furthermore, in 2022, 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 and CPI, 2023; IRENA, 2023a). 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 *et al.*, 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).

Every year, the gap between what is required and what is implemented continues to grow. IRENA's energy transition indicators (see Table 1) 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, 2022). The lack of progress will also increase future investment needs and the costs of worsening climate change effects.

TABLE 1 **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]	67%	91%	
	Renewable power capacity additions [27]	295 GW/yr [3]	975 GW/yr	1 066 GW/yr	
	Annual solar PV additions [27]	191 GW/yr [4]	551 GW/yr	615 GW/yr	
	Annual wind energy additions [27]	75 GW/yr [5]	329 GW/yr	335 GW/yr	
	Investment needs for RE generation	486 USD billion/yr [6]	1 300 USD billion/yr	1 382 USD billion/yr	
	Investment needs for power grids and flexibility	274 USD billion/yr [7]	548 USD billion/yr	790 USD billion/yr	
	DIRECT RENEWABLES IN END-USES AND DISTRICT HEAT				
	Share of renewables in final energy consumption	19% [8]	34%	83%	
	Solar thermal collector area	746 million m²/yr [9]	1 700 million m²/yr	3 700 million m²/yr	
	Modern use of bioenergy (direct use)	1.5 EJ [10]	44 EJ	56 EJ	
	Geothermal consumption (direct use)	0.4 EJ [11]	1.3 EJ	2.2 EJ	
	Renewables based district heat generation	0.9 EJ [12]	4.3 EJ	12 EJ	
	Investment needs for renewables end uses and district heat [28]	13 USD billion/yr [13]	269 USD billion/yr	216 USD billion/yr	

▶ continued

(contd.) TABLE 1 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	0.6 %/yr [14]	3.5 %/yr	2.9 %/yr	
ENERGY EFFICIENCY	Investment needs for energy conservation and efficiency [29]	295 USD billion/yr [15]	1772 USD billion/yr	1493 USD billion/yr	
ELECTRIFICATION	Share of direct electricity in final energy consumption	22 % [16]	29 %	51 %	
ELECTRIFICATION	Passenger electric cars on the road	10.5 million [17]	355 million	2 180 million	
ELECTRIFICATION	Investments needs for charging infrastructure of EV's and EV adoption support	30 USD billion/yr [18]	141 USD billion/yr	364 USD billion/yr	
ELECTRIFICATION	Investment needs for heat pumps	64 USD billion/yr [19]	266 USD billion/yr	258 USD billion/yr	
HYDROGEN	Clean hydrogen production	0.7 Mt/yr [20]	21.4 Mt/yr	518 Mt/yr	
HYDROGEN	Electrolyser capacity	0.5 GW [21]	233 GW	5 722 GW	
HYDROGEN	Investment needs for clean hydrogen and derivatives infrastructure [30]	1.1 USD billion/yr [22]	80 USD billion/yr	170 USD billion/yr	
HYDROGEN	Clean hydrogen consumption - industry [31]	0.04 EJ [23]	2.4 EJ	40 EJ	
CCS AND BECCS	CCS/CCU to abate emissions in industry	0.01 $GtCO_2$ captured/yr [24]	1.0 $GtCO_2$ captured/yr	3.0 $GtCO_2$ captured/yr	
CCS AND BECCS	BECCS and others to abate emissions in industry	0.002 $GtCO_2$ captured/yr [25]	0.7 $GtCO_2$ captured/yr	1.0 $GtCO_2$ captured/yr	
CCS AND BECCS	Investment needs for carbon removal and infrastructure	6.4 USD billion/yr [26]	18 USD billion/yr	107 USD billion/yr	

▶ Notes: see next page

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 the 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 environmental costs. 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.

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.

Table 1 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] 2022; [4] 2022; [5] 2022; [6] 2022; [7] 2022; [8] 2020; [9] 2021; [10] 2020; [11] 2020; [12] 2020; [13] 2022; [14] 2019; [15] 2021; [16] 2020; [17] 2022; [18] 2022; [19] 2022; [20] 2021; [21] 2022; [22] 2022; [23] 2021; [24] 2022; [25] 2022; [26] 2022; [27] net capacity additions for 2030 and 2050 are excluding replacement stock for end-of-life units; [28] future investments needed in renewables in end uses, district heating, biofuels and bio-based innovative fuels; [29] future investments in energy conservation and efficiency include those in bio-based plastics and organic materials, chemical and mechanical recycling and energy recovery; [30] future investments needed in electrolysers, infrastructure, H_2 stations, bunkering facilities and long-term storage; [31] future demand includes energy and non-energy uses. CCS = carbon capture and storage; CCU = carbon capture and use; BECCS = bioenergy, carbon capture and storage; EV = electric vehicle; RE = renewable energy; yr = year; m^2 = square meter; EJ = exajoule.

COP28 needs to catalyse a step change in actions to accelerate the energy transition.

The Global Stocktake at the 2023 United Nations Climate Change Conference (COP28) must serve as a catalyst for scaling up action over the following five years 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.

Energy efficiency, electrification, grid expansion and flexibility measures must be prioritised in the coming years. Energy efficiency in end-use sectors requires an average annual investment of USD 1.8 trillion under the 1.5°C Scenario. Electrification of end-use sectors, hydrogen, direct use of renewables and district heat will require an additional USD 0.75 trillion annually. Accelerated end-use sector electrification will need to be combined with a continuous drive to grow renewable power capacity, with an allocation of some USD 1.3 trillion annually. This growth requires commensurate electricity network expansion and modernisation, at a cost of USD 0.5 trillion annually. By comparison, cumulative annual investment in fossil fuel supply and power capacity in the same period would amount to USD 1 trillion, halving current trends.

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 (see Table 2).

TABLE 2 **Short-term measures to deal with the energy crisis and accelerate the energy transition**

Ambition	• Increase ambition of national renewable energy targets in line with climate goals, increased energy security and improved affordability. • Set ambitious renewable energy targets and energy efficiency targets in all end uses (electricity, heating and cooling, transport). • Develop effective implementation plans for all targets.
Institutions	• Make institutions fit for the transition: (*e.g.* new ministerial structures, cross-ministry task forces, updated statute for regulators). • Reform the existing lending practices of development finance institutions by providing more grants and concessional loans, particularly for countries that face under-investment and may be in debt distress.
Physical infrastructure	• Untertake integrated cross-sector infrastructure planning for the energy transition with ambitious targets for expansion (*e.g.* power grids, electric vehicle [EV] charging infrastructure, heat networks, all linked up to optimise variable renewable electricity). • Provide incentives for infrastructure investments where market barriers exist (*e.g.* heat networks, EV chargers). • Streamline permitting procedures for large-scale infrastructure without compromising environmental and social impact assessments and ensure public acceptance is fostered. • Set obligations or mandatory targets for new buildings (*e.g.* numbers of EV chargers per occupant, connection to heat networks). • Provide more public finance for the development of the infrastructure required (*e.g.* through direct ownership of assets such as transmission lines).
Jobs and skills	• Integrate renewable energy into educational curricula; expand technical and vocational education and training opportunities. • Step up efforts to anticipate future occupational needs in each renewable energy sector and work with industry associations and training institutions to align their planning. • Ensure better access to training opportunities for women, youth and minorities. • Develop pathways for fossil fuel industry workers to retrain and recertify for careers in renewable energy. This will require public funding for training.
Finance	• Increase and channel public financing – including through international collaboration via a broad spectrum of policies, covering all segments of the renewable energy value chain, the wider energy sector and the economy as a whole. • Strategically plan, select and implement instruments to channel public finance (domestic and international) including (1) government spending such as grants, rebates and subsidies; (2) debt including existing and new issuances, credit instruments, concessional/blended financing and guarantees; (3) equity and direct ownership of assets (such as transmission lines or land to build projects). • Define 'risk' in a more comprehensive way that goes beyond the narrow investor-centric definition of risk (*e.g.* of investment in energy assets not paying off) to include broader environmental and social risks. • Continue to use public policy and finance to crowd in private capital.

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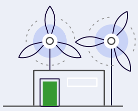
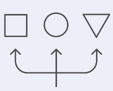
(contd.) TABLE 2 Short-term measures to deal with the energy crisis and accelerate the energy transition

Power sector 	• Adopt a power system structure that is conducive to high shares of variable renewable energy, recognising their techno-economic characteristics. This could include dual procurement of energy with long-term procurement through auctions and a short-term flexibility market. • Streamline permitting procedures for renewable power projects without compromising environmental and social impact assessment. Ensure public acceptance is fostered. • Better synchronise power grid expansion and other infrastructure developments with renewable power deployment to avoid bottlenecks. • Design renewable energy procurement processes (*e.g.* auctions) to serve objectives beyond lowest price (*e.g.* development of local industry) and consider design elements to distribute the risks of supply chain disruptions among stakeholders (*e.g.* indexation of components). • Design policies for self-consumption in a progressive way that supports equitable access to support for the deployment of solutions and the distribution of socio-economic benefits.
End-use sectors – buildings, industry, transport 	• Develop energy efficiency programmes and measures such as standards in transport, industry, and buildings. Increase finance for energy efficiency through efforts to aggregate projects and de-risk investment. • Promote readiness for new fuels and electrification (*e.g.* EV chargers, see also *Physical Infrastructure*). • Behaviour changes: incentivise slower driving using speed limits, mandate room temperature limits (*e.g.* offices and public buildings), reduce individual car usage by promoting public transport and car-sharing; prefer high-speed and night trains to aircraft where possible.
Cross-sector and cross-cutting policies 	• Introduce fiscal policy measures: obligations for reinvesting windfall profits of fossil fuel energy revenues in energy transition technologies, reduced subsidies for fossil fuels and raised/newly introduced CO_2 prices when fossil fuel prices fall. Ensure the socio-economic benefits of such instruments are distributed fairly. Reform taxes and levies on heating fuels, VAT exemptions for renewables, *etc.* • Develop national bioenergy and/or hydrogen strategies (including sectoral prioritisation) to ensure bioenergy and hydrogen can play the most appropriate role in decarbonisation. • Incentivise/mandate a circular economy approach (reduce, re-use, recycle), for example for energy-intensive products like steel, renewable energy technologies, batteries, cars, *etc.* This will both reduce energy demand and the demand for critical materials. • Enhance international collaboration across a range of relevant areas including sustainability governance, energy and climate finance, technology and innovation, regional power grids, green hydrogen development. • Put greater focus (including through international collaboration) on achieving the universal access targets of SDG7.

DEVELOPING STRUCTURES FOR A RENEWABLES-BASED ENERGY SYSTEM

A profound and systemic transformation of the global energy system must occur within 30 years. This condensed timeframe necessitates a strategic shift that expands beyond the focus on decarbonisation of supply 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 demand for clean energy and 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 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. Switching the focus from fuels to systems design will help accelerate the development of a new energy infrastructure and sustain its implementation.

The energy transition can support a move toward a more resilient and equitable world.

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 toward a more resilient and equitable world. These underpinnings should form the pillars of the structure that supports the energy transition as follows:

PHYSICAL INFRASTRUCTURE: forward-looking planning, modernisation and expansion of supporting infrastructure on land and sea to facilitate the development, storage, distribution and transmission, and consumption of renewables. It should facilitate national, regional and global strategies for new supply-demand dynamics and promote equity and inclusion.

POLICY AND REGULATORY ENABLERS: design of policy and regulatory frameworks that facilitate deployment, integration and trade of renewables-based energy, shape socio-economic outcomes and promote equality. These need to enable different levels of the energy transition, from local to global, and account for new supply-demand dynamics.

WELL-SKILLED WORKFORCE: capacity among institutions, communities and individuals to acquire the requisite skills, knowledge and expertise to drive and sustain the energy transition. An integral aspect of this will be ensuring that communities are well informed of, and able to exercise, their rights as critical transition stakeholders, and to harness its benefits.

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. Work by IRENA and the International Labour Organization (ILO) has shown that the renewable energy sector employed some 12.7 million people worldwide as of 2022, growing from about 7.3 million in 2012. Energy transition modelling indicates that tens of millions of additional jobs will likely be created in the coming decades as investments grow and installed capacities expand. 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 educational 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.

THE WAY FORWARD PRIORITISING BOLD AND TRANSFORMATIVE ACTIONS

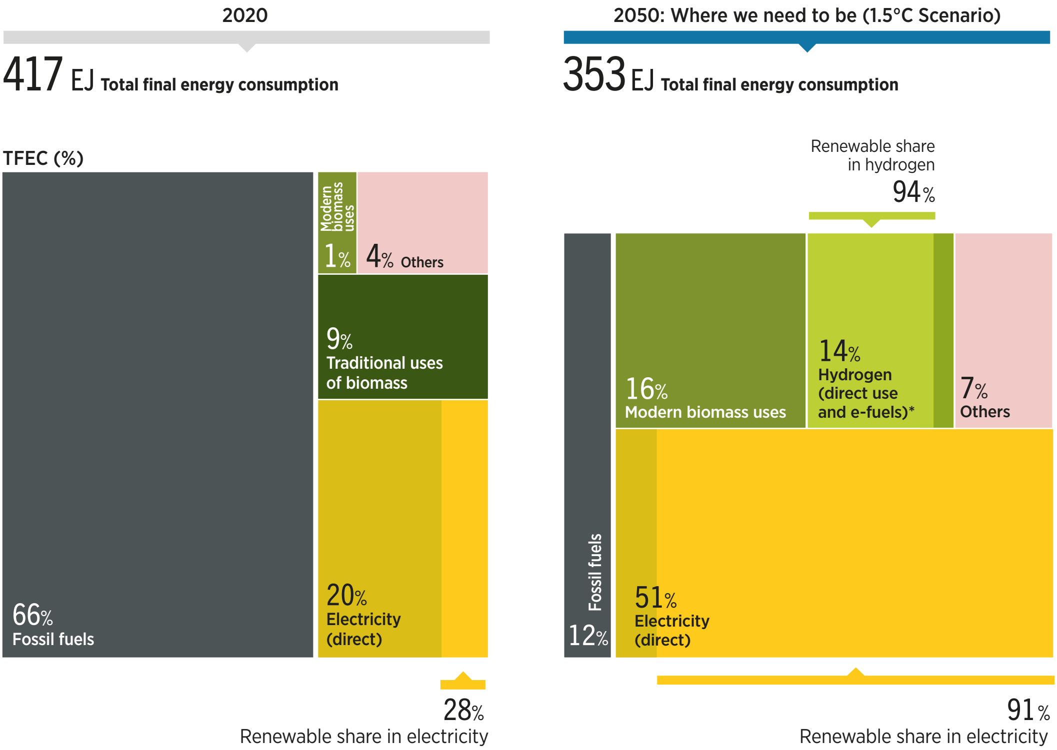
Net-zero commitments must be embedded in legislation and translated into implementation plans that are adequately resourced. Without this crucial step, climate announcements remain aspirational, and the necessary progress out of reach. The current energy system is deeply woven into socio-economic structures 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.

Energy infrastructure is long-lived, so investment in fixed infrastructure should consider the long term. Every investment and planning decision around energy infrastructure today should consider the structure and geography of the low-carbon economy of the future. 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.

Energy investment decisions should simultaneously drive the transition and reduce the risk of stranded assets. The Planned Energy Scenario foresees cumulative energy sector-wide investments of USD 103 trillion between 2023 and 2050, or USD 3.7 trillion annually, on average, to 2050. Around 59% of this investment is intended for energy transition technologies - mostly for renewables, energy efficiency, electrification, hydrogen, and carbon removals. However, some 41% of planned energy investment remains aimed at fossil fuels; therefore, a combination of scale-up and re-allocation of investment in energy transition technologies is needed to keep the 1.5°C target within reach.

The 1.5°C Scenario envisages electricity becoming the main energy carrier, accounting for over 50% of total final energy consumption (see Figure 3). Renewable energy deployment, improvements in energy efficiency and the electrification of end-use sectors contribute to this shift. In addition, modern biomass and hydrogen are projected to play more significant roles, with 16% and 14% of total final energy consumption by 2050, respectively. Notably, 94% of hydrogen consumption is expected to come from renewables, indicating a growing reliance on clean energy sources. The pathway also suggests that total final energy consumption could decrease by 15% from 2020 to 2050, potentially indicating a trend towards decarbonisation and a more sustainable energy future.

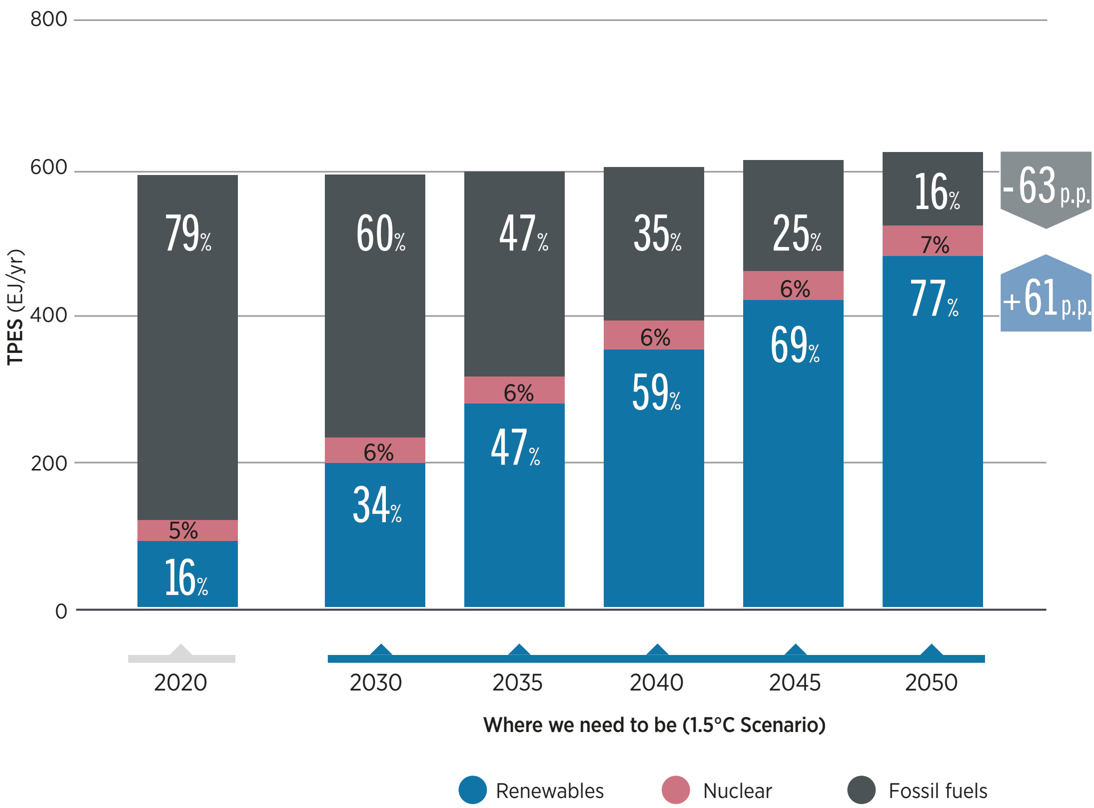
FIGURE 3 **Breakdown of total final energy consumption by energy carrier between 2020 and 2050 under the 1.5°C Scenario**



Notes: The figures above include only energy consumption, excluding non-energy uses. For electricity use, 28% in 2020 and 91% in 2050 are sourced from renewable sources; for district heating, the shares are 7% and 95%, respectively; for hydrogen (direct use and e-fuels), the renewable energy share (*i.e.* green hydrogen) would reach 94% by 2050. The category Hydrogen (direct use and e-fuels) accounts for total hydrogen consumption (green and blue) and other e-fuels (e-ammonia and e-methanol). Electricity (direct) includes the consumption of electricity that is provided by all sources of generation: renewable, nuclear and fossil fuel based. Traditional uses of biomass refer to the residential TFEC of solid biofuels in non-OECD countries. Modern bioenergy uses include solid biomass, biogas and biomethane used in buildings and industry; and liquid biofuels used mainly in transport, but also in buildings, industry and other final consumption. Remaining fossil fuels in 2050 correspond to natural gas (mainly used in industry and transport, and to a lesser extent in buildings), oil (mainly in industry and transport, and to a lesser extent in buildings) and coal (corresponds to uses in industry - cement, chemicals, iron and steel). Others include district heat and other renewables consumption. EJ = exajoule; OECD = Organisation for Economic Co-operation and Development; TFEC = total final energy consumption.

The share of renewable energy in the world's primary energy supply grows from 16% in 2020 to 77% in 2050 under the 1.5°C Scenario, requiring an annual growth rate thirteen times the current rate (Figure 4). This growth is expected to stabilise primary energy supply due to increased energy efficiency and the growth of renewables. The energy mix will change drastically in the process, with a net gain of 61 percentage points of renewable energy share, driven by a mix of end-use electrification, renewable fuels and direct use. Achieving this level of renewable energy penetration is critical to meeting global climate goals and will require significant investment and policy support, as well as continued innovation.

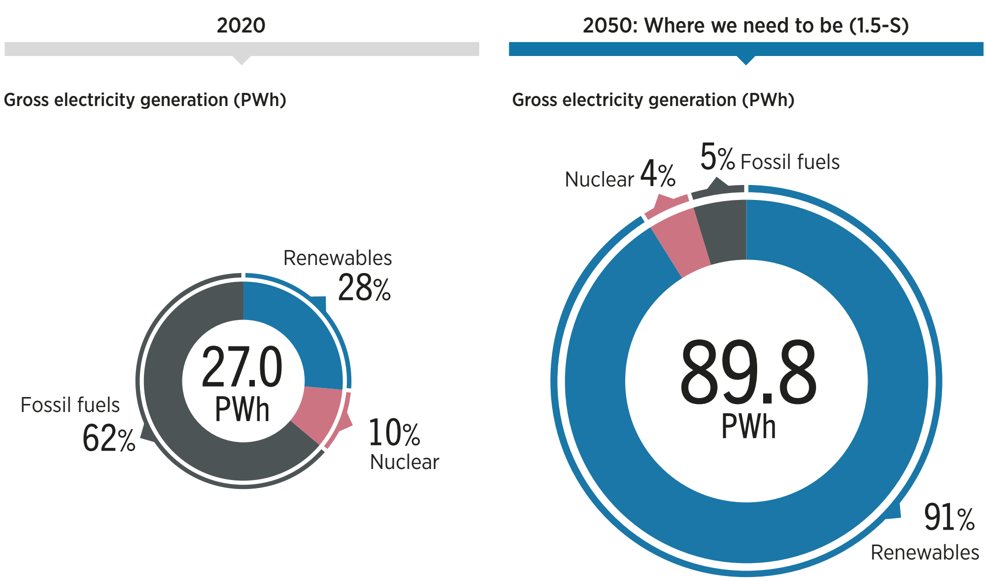
FIGURE 4 **Total primary energy supply by energy carrier group, 2020-2050 under the 1.5°C Scenario**



Note: Renewables include bioenergy, geothermal, hydropower, ocean, solar and wind in all forms (electricity and synthetic fuels). Fossil fuels include coal, oil and natural gas; p.p. = percentage points.

Electricity generation will more than triple from 2020 to 2050, with 91% of the total electricity supply coming from renewable sources, compared to 28% in 2020 (see Figure 5). Coal- and oil-based power generation will experience a sharp decline over the decade before being phased out entirely by mid-century. By 2050, natural gas will provide 5% of total electricity needs, with the remainder being met by nuclear power plants. The transition features an important synergy between increasingly affordable renewable power technologies and the wider adoption of electric technologies for end-use applications, especially in transport and heat.

FIGURE 5 Power generation needs to more than triple by 2050



Notes: PWh = petawatt hours.

By 2050, most of the world's power will be generated from renewable sources.

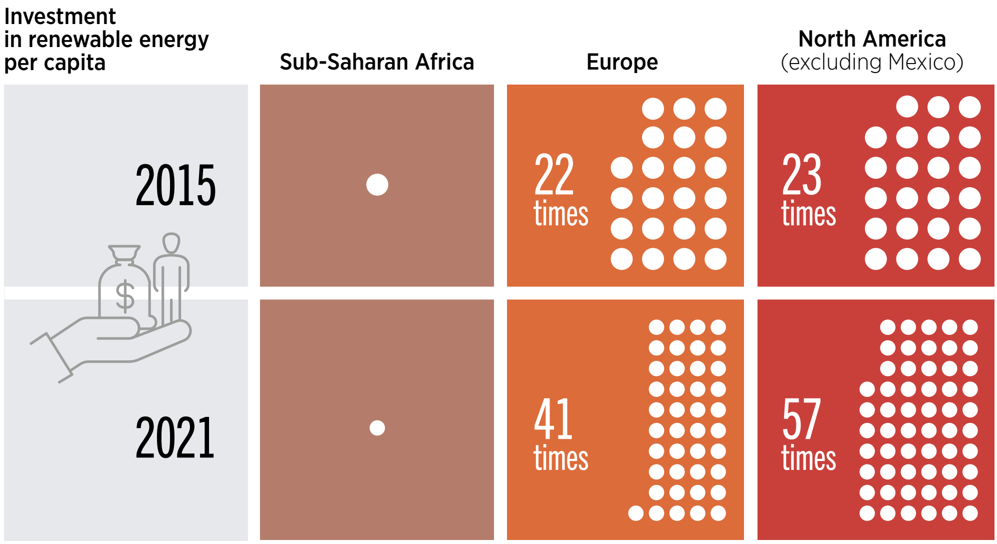
Public financing has a critical role to play to help achieve a just and inclusive energy transition.

Public investment strategies play a critical role in accelerating the speed of the energy transition. Such investments need to not only increase in volume, but also be allocated strategically to guide private investment decisions and serve as an effective instrument to shape the energy transition in ways that maximise benefits in the public interest. In addition, public procurement programmes are best placed to set standards so that energy projects adhere to labour standards and environmental safeguards.

Stronger public sector intervention is required to channel investments towards countries and technologies in a more equitable way. Some 75% of global investment in renewables from 2013 to 2020 came from the private sector; but 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 & CPI, 2023). The greater need for public finance in hydropower is linked to large upfront investments, high construction risks, the need for long-tenor loans (as projects can take over a decade to complete), complex and lengthy permitting procedures, and high social and environmental risks, all of which can significantly hamper the ability of the private sector to finance large hydropower projects (IRENA, 2023b). For geothermal, meanwhile, the high costs of surface exploration and drilling represent the main obstacles to private sector financing.

Public finance and policy should continue to be used to 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 will continue to widen. In 2015, renewable energy investment per capita in North America (excluding Mexico) and Europe was around 22 times higher than in Sub-Saharan Africa. But by 2021, investment per capita in Europe had risen to 41 times that in Sub-Saharan Africa, and in North America it was 57 times more (see Figure 6). This is partly explained by the fact that Sub-Saharan Africa investment per capita in 2021 had fallen to almost half its 2015 value of USD 6 per person (IRENA and CPI, 2023).

FIGURE 6 **Growing disparities in per capita investment between Sub-Saharan Africa, Europe and North America**



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**

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 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.

The expanding variety of actors 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 at 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 & 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.

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.

This preview presents high-level insights from the forthcoming 2023 report, which 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 – that is, 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 at the necessary pace to meet the 1.5°C goal.

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PREVIEW