IRENA
International Renewable Energy Agency

WORLD ENERGY TRANSITIONS OUTLOOK

1.5°C PATHWAY

EXECUTIVE SUMMARY

FOREWORD

We have no time. The window is closing and the pathway to a net zero future is narrowing. This was the message I delivered plainly and unambiguously when we released the *World Energy Transitions Outlook* preview at the Berlin Energy Transitions Dialogue earlier this year. Science is clear: 45% of global greenhouse gas emissions from 2010 levels must be reduced by 2030. Unfortunately, the recent trends show that the gap between where we are and where we should be is widening. We are on the wrong path, and we need to change the course now.

The choices we make in the coming years will have a far-reaching impact. They could bring us on a path toward the goals we set out in 2015 when we adopted the highly consequential international agreements on sustainable development and climate change. Or they could take us in the opposite direction to further warming, with profound and irreversible economic and humanitarian consequences.

It is unwise to make predictions or pre-empt outcomes at uncertain times. But several trends are shaping an unfolding energy transition and giving an indication of its direction. First, the costs of renewable technologies have plummeted to the point that new fossil-based electricity is no longer an attractive option. Second, the progress in the power sector is spilling over to end uses, allowing a re-imagining of possibilities with the abundance of renewable options at hand. Third, a consensus has formed that an energy transition grounded in renewable sources of energy and efficient technologies is the only way to give us a fighting chance of limiting global warming by 2050 to 1.5°C. Only a few years ago, the renewables-centred approach espoused by IRENA was considered too progressive, idealistic or even unrealistic. Today, our vision has become mainstream, and accepted as the only realistic option for a climate-safe world. And this is reflected in the growing number of commitments to net zero strategies by countries in all corners of the world, creating unprecedented political momentum for a transformative change.

IRENA's *World Energy Transitions Outlook* outlines the avenues to take us out of the climate crisis toward a resilient and more equitable world. It clearly shows the options we have today and what gaps need to be filled. The analysis and options presented prioritise existing emission-reduction solutions and those with the highest chance to become viable in the coming years. It does not bet on unproven technologies or pending inventions but encourages much-needed innovation to perfect and advance the fastest path to emission reduction.

The Outlook offers a compelling path for decarbonising all energy uses, with electrification and energy efficiency as primary drivers, enabled by renewables, green hydrogen and sustainable modern bioenergy. But a scenario and its assumptions, however rigorous and comprehensive, are only an instrument to inform policy making. To translate this vision of the energy future into reality, we need to transcend the limits of the existing infrastructure created for the fuels of the past. And these decisions are not made in a vacuum. Economic and human development goals, environmental concerns, and financial avenues must all be reconciled.

It is in this context that IRENA brings its unique value.

The Outlook shows that, when we look beyond the narrow confines of energy supply, a renewables-based transition unlocks a range of valuable benefits. The Outlook thus presents the policy frameworks necessary to advance a transition that is just and inclusive. It provides an improved understanding of structural changes and offers a quantitative framework for impacts such as gross domestic product (GDP), employment and welfare. The report also examines funding structures to show the necessary shift in capital markets.

And this knowledge provides the basis for IRENA to support countries in realising their priorities and turning their strategies into action. With our 164 Members, we see how collective action can drive progress worldwide and where overarching needs and gaps may exist.

This global reach is what gives the Agency the credibility - and privilege - to support international co-operation across the gamut of energy transition issues to help countries learn from each other and tap into the vast expertise of the Agency. And we are actively working with partners, including the private sector, to provide a dynamic platform that drives action, foresighted planning, holistic policy making and investment at scale.

The demands of our time are great and full of uncertainty. We are entering a new era of change, one in which energy transformation will drive economic transformation. This change is bringing unprecedented new possibilities to revitalise economies and lift people out of poverty. But the task ahead is daunting. I hope that this Outlook provides a fresh view on how to turn today's energy problems into tomorrow's solutions.

Our shared future will only be bright if we move together, taking everyone along towards a more resilient, equal, and just world.

Francesco La Camera
Director-General, IRENA

EXECUTIVE SUMMARY

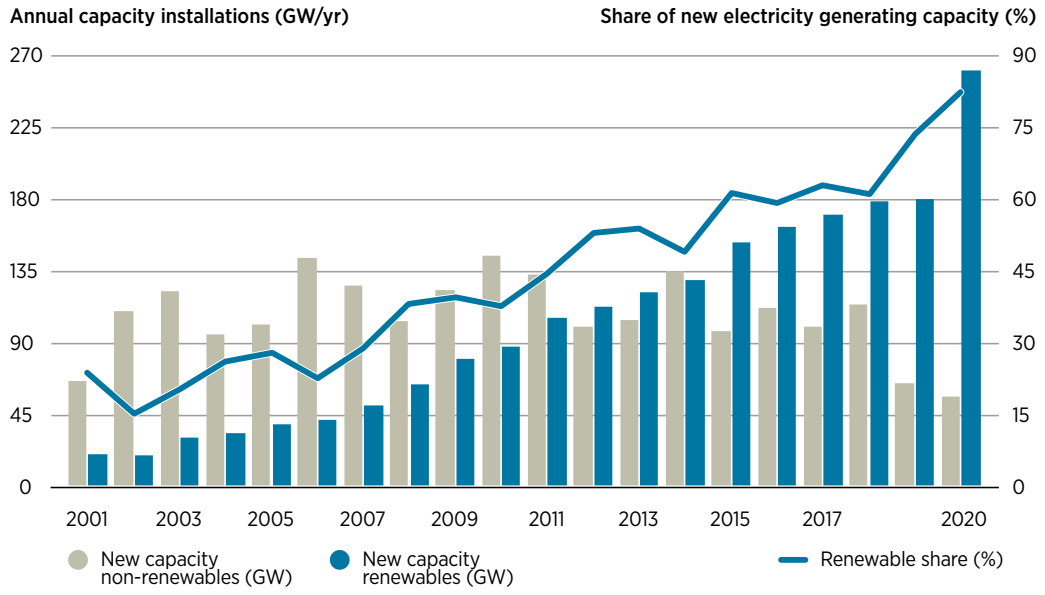
Where are we in the energy transition?

The energy sector, known for its slow pace of change, is undergoing a dynamic transition. The imperatives of climate change, energy poverty and energy security to underpin development and industrial strategy have made the widespread adoption of renewables and related technologies an essential solution. Policy drivers, technology developments and international co-operation have moved these technologies from niche to mainstream, especially in the past decade. Even in the face of the turmoil caused by the COVID-19 pandemic, renewables-based systems demonstrated remarkable resilience, showing technical reliability of renewables-based electricity system with high share of solar and wind.

A consensus has formed that an energy transition grounded in renewable sources and technologies that increases efficiency and conservation is the only way to give us a fighting chance of limiting global warming to 1.5°C by 2050. Only a few years ago, the renewables-centred approach espoused by IRENA was considered idealistic. Today, even some of the most conservative energy players have realised it as the only realistic option for a climate-safe world. Such a profound and pervasive shift of views is rooted in undeniable evidence, not only of the world's grave problems, but also of trends in technology, policy and markets that have been reshaping the energy sector for over a decade.

For the past seven years, more renewable power was added to the grid annually than fossil fuels and nuclear combined. Renewable power technologies now dominate the global market for new electricity generation capacity, as they have become the cheapest sources of electricity in many markets. A record level of 260 gigawatts (GW) of renewables-based generation capacity was added globally in 2020, more than four times the capacity added from other sources (IRENA, 2021a). This a promising trajectory for rapid decarbonisation of the power sector.

FIGURE S.1 Share of capacity, 2001-2020

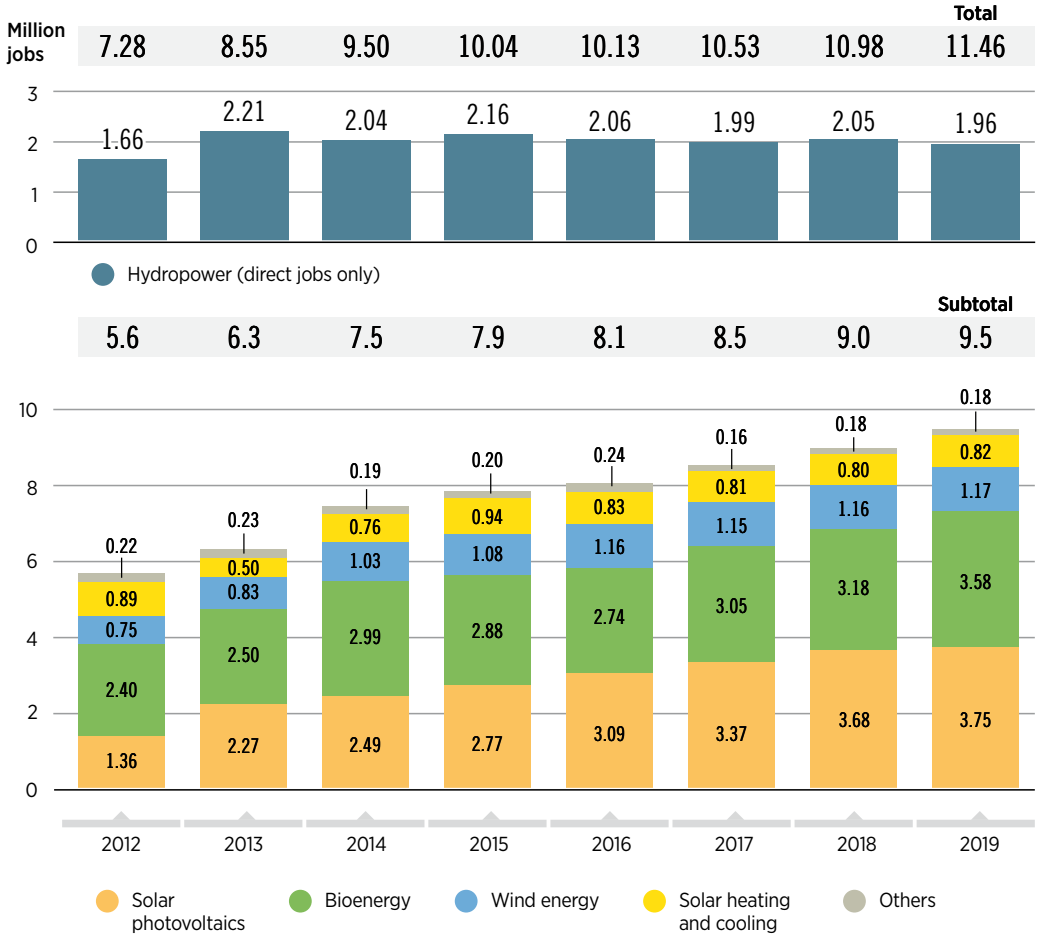


Based on IRENA's renewable energy statistics.

Innovative solutions are reshaping the energy system and opening new possibilities for a decarbonised future much faster than expected. Innovations in technology, policy and markets are being implemented worldwide (IRENA, 2019a). Significant progress has been made in electric mobility, battery storage, digital technologies and artificial intelligence, among others. These shifts are also drawing greater attention to the need for sustainable exploitation and management of rare earths and other minerals, and investment in the circular economy. New and smart grids, ranging from mini- to super grids, bolstered by facilitative policies and markets, are enhancing the power sector's ability to cope with the variability of renewables. Direct uses of renewables – including bioenergy – and green hydrogen are bringing much-needed solutions in transport, buildings and industry.

Of the 58 million energy jobs worldwide in 2019, some 20% were in the renewable sector. The change in global employment patterns reflects new trends in energy deployment. Employment grew from 7.3 million in 2012, when IRENA began monitoring jobs in renewables, to 11.5 million in 2019. During the same period, energy jobs were decreasing owing to growing automation, lack of competitiveness of some fuels and changing market dynamics. There is also growing evidence of the wider impacts of the shift toward renewables. Notably, the rise of renewables has improved the gender balance in the energy sector, with women accounting for 32% of jobs in renewables, compared with 22% in the oil and gas.

FIGURE S.2 Global renewable energy employment by technology, 2012-2019



Source: IRENA, 2020a.

The growing number of countries committing to net zero carbon strategies indicates a major shift in the global climate discourse. Similar trends are observed at all levels of government and in the private sector, including in hard to abate and oil and gas sectors. As much of the world grapples with the economic downturn, investment in the energy transition can help align short-term priorities with medium- and long-term development and climate objectives. This is a unique opportunity to instigate a lasting shift with foresighted and targeted investment in energy, most immediately in infrastructure, efficiency and renewables (IRENA, 2020b). Indeed, several countries have made significant commitments to appropriate public funds for these purposes and to support solutions such as electric mobility and clean hydrogen.

No less than 80% of the world's people live in countries that are net importers of fossil fuels. By contrast, every nation possesses some renewable potential that can be harnessed for greater energy security and independence, increasingly at least cost (IRENA, 2019b). A transformation of the global energy system aligned with the 1.5°C climate goal can become a great equaliser in a world that must become more resilient, just and inclusive. Such an energy system requires the rapid development and deployment of resilient technologies and investments in people and institutions.

Progress has been significant but uneven across geographies and communities. The longest strides have been made in a handful of countries and regions. In other areas, widespread energy poverty continues to hold back economic progress and social wellbeing. In 2020, Europe, U.S. and China accounted for the largest share of new renewable capacity, while Africa accounted for only 1% of the global total of new renewable capacity. This is even though the continent has the largest needs for expanded access to modern forms of energy and a renewable potential that far exceeds projected needs. Only USD 1 billion was invested in off-grid renewables between 2008 and 2019, despite being a major avenue for expanding access. Uneven deployment patterns are also mirrored in the concentration of jobs and industries, leaving behind large parts of the world.

Current plans fall woefully short of a 1.5°C goal. Based on existing government energy plans and targets, including the first round of Nationally Determined Contributions (NDCs) under the Paris Agreement, the policies in place will do no more than stabilise global emissions, with a slight drop as 2050 approaches. Despite clear evidence of human-caused climate change, widespread support for the Paris Agreement, and the prevalence of clean, economical, and sustainable energy options, energy-related CO_2 emissions *increased* by 1.3% annually, on average, between 2014 and 2019.

Time is of the essence, and a rapid decline in emissions must begin now to preserve a fighting chance to hold the line at 1.5°C. In alignment with the Intergovernmental Panel on Climate Change's (IPCC) report on limiting global warming to 1.5°C by 2050, coal and oil should already have peaked, with natural gas peaking in 2025. The resources and technologies needed to accelerate the energy transition are available *now*. IRENA plots the way to a steep and continuous downward trajectory towards a 45% decline in carbon dioxide (CO_2) emissions from 2010 levels by 2030, and net zero by 2050, in line with IPCC's schedule.

IRENA's *World Energy Transitions Outlook* is a unique 1.5°C-compatible pathway that also examines full socio-economic and policy implications, and provides insights on the structural changes and finance. Technologies for rapid decarbonisation are increasingly available, but thinking related to the energy transition should not be confined within the energy silo. Realising the transition's far-reaching potential requires systemic innovation that considers technologies and enabling frameworks in tandem. Renewables-based energy systems will instigate profound changes that will reverberate across economies and societies. Only by understanding these deep currents can we achieve optimal results from the transition process. This inaugural edition of the *World Energy Transitions Outlook* marshals IRENA's extensive knowledge to make this possible – by providing policy makers with insights, tools and advice to chart the path ahead.

IRENA's 1.5°C Scenario

The **Planned Energy Scenario (PES)** is the primary reference case for this study, providing a perspective on energy system developments based on governments' current energy plans and other planned targets and policies, including Nationally Determined Contributions (NDCs) under the Paris Agreement.

PES

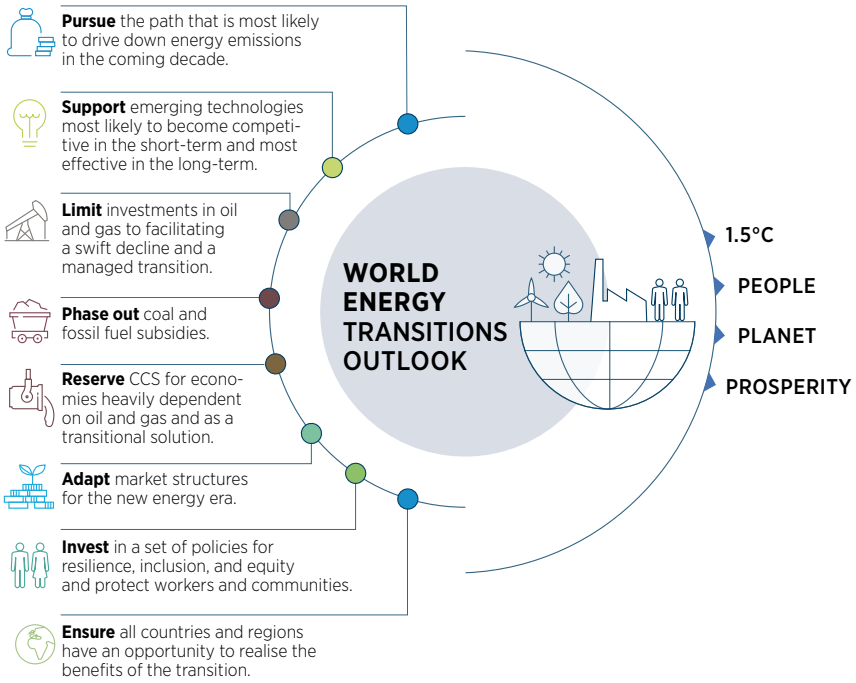
The **1.5°C Scenario (1.5-S)** describes an energy transition pathway aligned with the 1.5°C climate ambition – that is, to limit global average temperature increase by the end of the present century to 1.5°C, relative to pre-industrial levels. It prioritises readily available technology solutions, which can be scaled up at the necessary pace for the 1.5°C goal.

1.5-S

The time imperative requires careful investment and policy choices in the coming decade. The window of opportunity to achieve the 2030 emission milestone set out by the IPCC is small, and the choices made in the coming years will determine whether a 1.5°C future remains within reach. This *Outlook* is guided by the UN's Agenda for Sustainable Development and the Paris Agreement on Climate Change. Several prerequisites underpin the theory of change behind IRENA's 1.5°C Pathway:

- Pursuing the path that is most likely to drive down energy emissions in the coming decade and put the world on a 1.5°C trajectory.
- Supporting emerging technologies most likely to become competitive in the short-term and most effective in achieving emissions reductions in the long-term.
- Limiting investments in oil and gas to facilitating a swift decline and a managed transition.
- Reserving carbon capture and storage technologies for economies heavily dependent on oil and gas and as a transitional solution where no other options exist
- Phasing out coal and fossil fuel subsidies.
- Adapting market structures for the new energy era.
- Investing in a set of policies to promote resilience, inclusion, and equity and protect workers and communities affected by the energy transition.
- Ensuring all countries and regions have an opportunity to participate in and realise the benefits of the global energy transition.

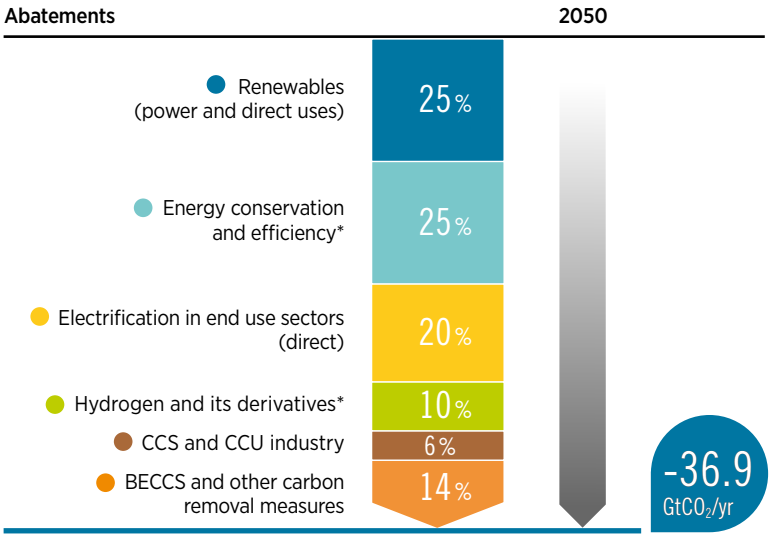
FIGURE S.3 Guiding framework of WETO theory of change



Technological avenues to climate targets

IRENA's analysis shows that over 90% of the solutions shaping a successful outcome in 2050 involve renewable energy through direct supply, electrification, energy efficiency, green hydrogen and bioenergy combined with carbon capture and storage (BECCS). The technological avenues leading to a decarbonised energy system have crystalised, dominated by solutions that can be deployed rapidly and at scale. Technologies, markets, and business models are continuously evolving, but there is no need to wait for new solutions. Considerable advancement can be achieved with existing options. But taking the energy transition technologies to the necessary levels, and at a speed compatible with a 1.5°C goal, requires targeted policies and measures.

FIGURE S.4 Carbon emissions abatements under the 1.5°C Scenario (%)



By 2050, electricity will be the main energy carrier, increasing from a 21% share of total final energy consumption in 2018 to over 50% in 2050. Sectoral boundaries are shifting, with the electrification of end-use applications in transport and heating. This increase is mostly driven by the use of renewable electricity in place of fossil fuels in end-use applications. As this shift occurs, the annual growth rate of renewable technologies will see an eightfold increase. Electrification of end-uses will also reshape several sectors, most notably transport, with electric vehicles coming to account for 80% of all road activity in 2050.

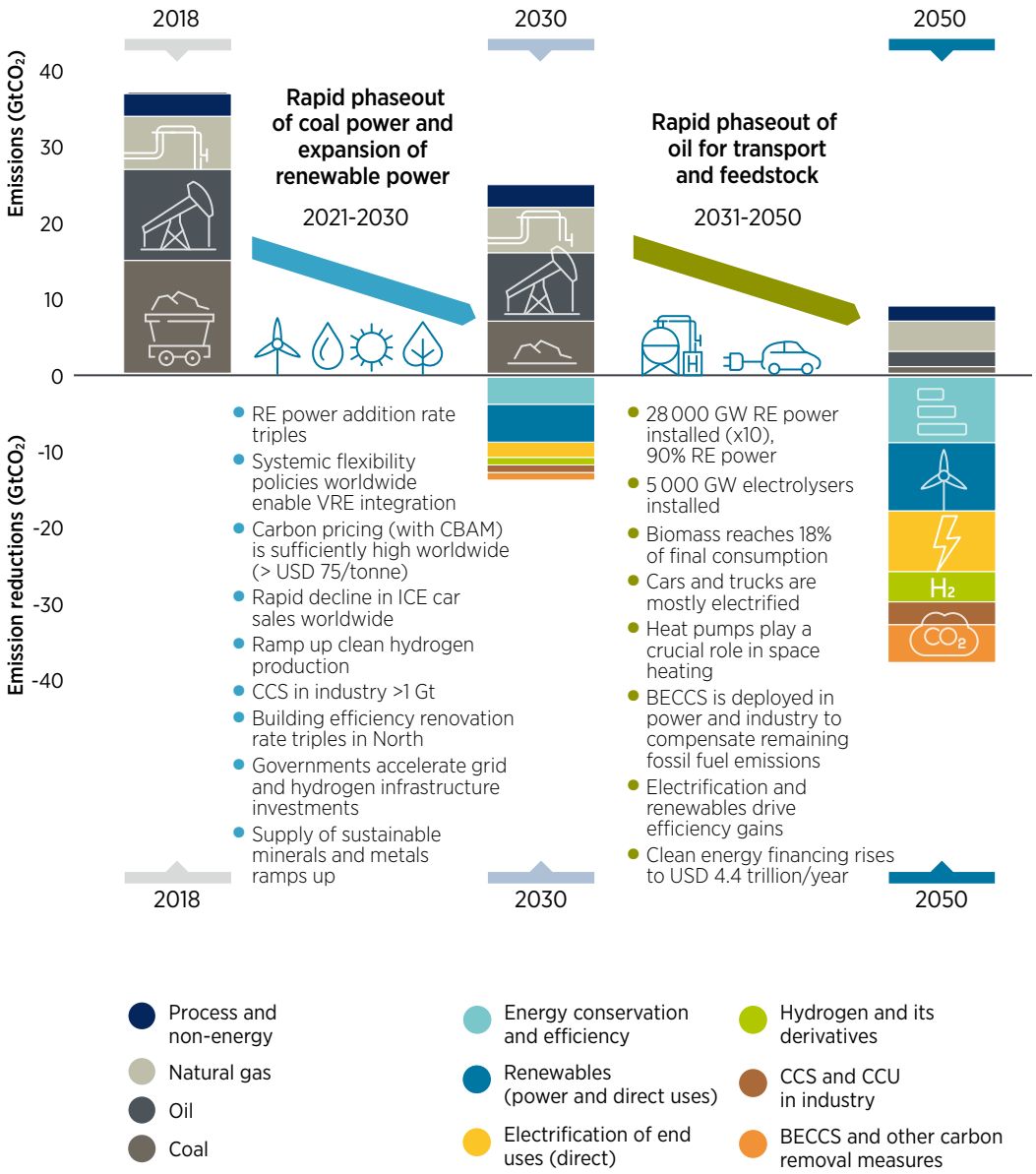
The annual energy intensity improvement rate needs to rise to 2.9%, nearly two and a half times the historical trend. With this rise, the energy intensity of the global economy will fall more than 60% by 2050. Energy efficiency technologies and measures are "ready-to-go" solutions, available for significant scale-up now. Policies and measures to increase energy conservation and efficiency will be crucial to reduce total final energy consumption from 378 exajoule (EJ) in 2018 to 348 EJ in 2050. An important contribution will also come from structural and behavioural changes, which will account for about a tenth of the improvement in efficiency.

Hydrogen and derivatives will account for 12% of final energy use by 2050. They will play an important role in hard-to-decarbonise, energy-intensive sectors like steel, chemicals, long-haul transport, shipping and aviation. Hydrogen will also help balance renewable electricity supply and demand and serve as long-term seasonal storage. Some 5 000 GW of electrolyser capacity will be needed by 2050, up from 0.3 GW today. This scale of growth accentuates the importance of low-carbon hydrogen from the outset. In 2050, two-thirds of the total hydrogen will be green – produced with renewable electricity – and one-third blue, produced by natural gas coupled with carbon capture and storage (CCS).

Bioenergy will represent 18% of total final energy consumption in 2050. Increasing sustainable production and use of biomass is needed across the energy system. In some sectors, it plays a significant role – particularly as feedstock and fuel in the chemicals sectors and as fuel in the aviation sector. In others, it helps to address gaps that other options cannot fully resolve, such as replacing natural gas with biomethane in buildings that cannot be renovated. Additionally, biomass coupled with CCS (BECCS) in the power sector and some industrial sectors will deliver the negative emissions needed to achieve the net zero goal.

In residual use of fossil fuels and some industrial processes, decarbonisation efforts may require CCS and CO_2 removal technologies and measures. In the 1.5°C Scenario, some emissions persist in 2050 from residual uses of fossil fuels and some industrial processes. Therefore, the remaining CO_2 will have to be captured and sequestered. CCS is limited mainly to process-related CO_2 emissions in cement, iron and steel, and blue hydrogen production. CO_2 removal includes nature-based measures such as reforestation and BECCS, direct carbon capture and storage, and other approaches that are still experimental.

FIGURE S.5 Evolution of emissions with phaseouts of coal and oil, 2021-2050



Note: RE = renewable energy; VRE = variable renewable energy; CBAM = carbon border adjustment mechanism; ICE = internal combustion engine; GW = gigawatt; Gt = gigatonne; CCS = carbon capture and storage; BECCS = bioenergy combined with carbon capture and storage; CCU = carbon capture and utilisation.

By 2030, renewable power should reach 10 770 GW globally, almost quadrupling the current capacity. Rapid scale-up deployment in the coming decade is necessary to set the stage for decarbonisation of the power system and electrification of end-use by 2050. This level of deployment is also a key recommendation of the Energy Transitions Theme Report, developed by IRENA, UNEP, and UN ESCAP for the United Nations High-Level Energy Dialogue. The abundance of cost-effective renewable potentials worldwide makes them a scalable option. For many countries, this translates a technical and economic challenge into a set of investment, regulatory and societal opportunities.

Infrastructure upgrade, modernisation and expansion is a high priority in the coming decade. Updating ailing infrastructure or investing in expansion is an integral part of the energy transition and an enabler of modern technologies. This will be particularly important in the coming decade as the share of renewables grows, requiring system flexibility and modern grids. Infrastructure developments must be aligned with long-term plans and reflective of broader strategies, including regional market integration.

The necessary deployment levels will be reached by 2030 only with policies to support these technological avenues. Deployment policies support market creation, thus facilitating scale-up, reducing technology costs and increasing investment levels aligned with energy transition needs. Given the large amounts of public finance being injected into economies as part of the recovery measures, such policies will shape the direction of the energy transition and set the stage for the significant increase in the private sector investment required until 2050.

TABLE S.1 Overview of policies to support energy transition solutions

TECHNO-LOGICAL AVENUE	OBJECTIVE	RECOMMENDATIONS
Renewables (power and direct uses)	Deploy renewable energy in end uses	These policies include regulatory measures that create a market, as well as fiscal and financial incentives to make them more affordable and increase their cost competitiveness compared to fossil-fuel-based solutions.
	Deploy renewable energy in the power sector	The choice of instrument and its design should consider the nature of the solution (*e.g.*, utility scale, distributed, off-grid), the sector's level of development, the power system's organisational structure and broader policy objectives.
Energy conservation and efficiency	Increase energy conservation and efficiency in heating and cooling	Energy efficiency policies such as strict building codes, support for building retrofits and appliance standards are critical for the energy transition in buildings and industrial processes.
	Increase energy conservation in transport	Decarbonising the transport sector, among other measures, requires a shift from energy-intensive modes to low-carbon modes.
Electrification of end uses	Electrify heating and cooling	Targets for renewable power should consider the rising demand from the electrification of end uses, in line with long-term decarbonisation objectives. Moreover, policies and power system design are needed to support electrification in achieving its potential for providing system flexibility.
	Electrify transport	
Green hydrogen	Support the development of green hydrogen	An enabling policy framework should consider four key pillars: a national green hydrogen strategy, priority setting, guarantees of origin and enabling policies.
Sustainable bioenergy	Ensure the sustainable use of bioenergy	Renewable energy is not exempt from sustainability concerns. Some of these concerns include greenhouse gas emissions related to land-use change, and impacts on air and water quality and biodiversity.

Financing the energy transition

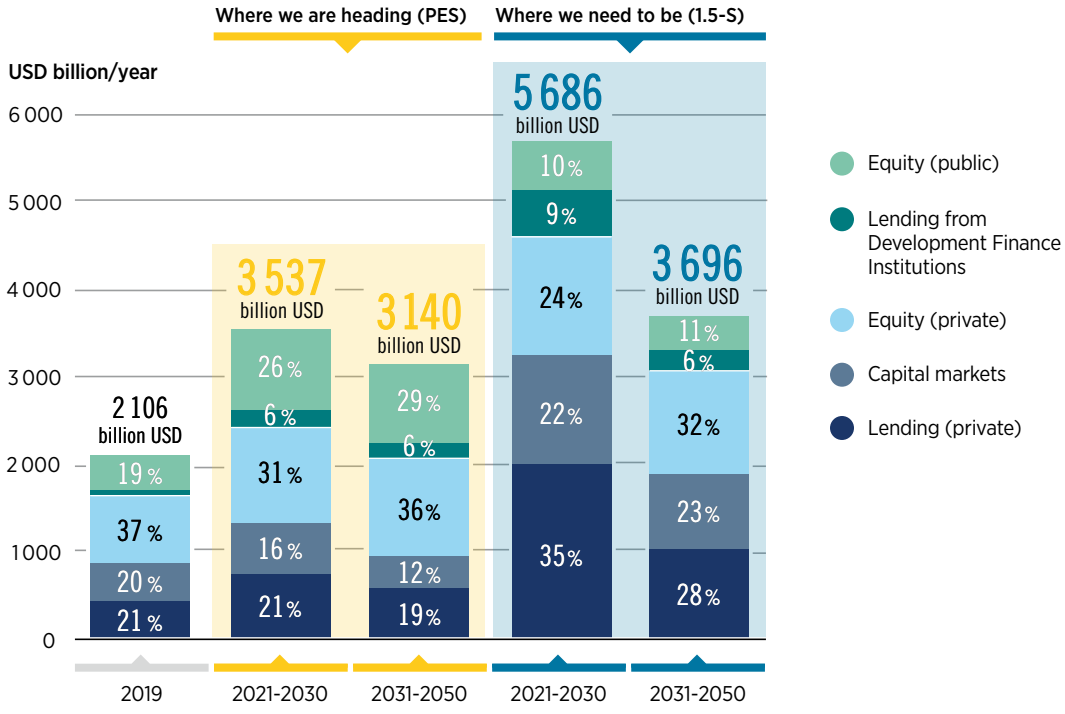
USD 131 trillion will need to flow into an energy system over the period to 2050 that prioritises technology avenues compatible with a 1.5°C Pathway. While the annual funding requirement averaging at USD 4.4 trillion is large, it represents 20% of the Gross Fixed Capital Formation in 2019, equivalent to about 5% of global Gross Domestic Product (GDP). Between now and 2050, over 80% of the USD 131 trillion total must be invested in energy-transition technologies, including efficiency, renewables, end-use electrification, power grids, flexibility, hydrogen, and innovations designed to help emerging and niche solutions become economically viable.

Current government strategies already envisage significant investment in energy amounting to USD 98 trillion by 2050. Collectively referred to in this Outlook as the Planned Energy Scenario (PES), they imply a near doubling of annual energy investment, which in 2019 amounted to USD 2.1 trillion. Substantial funds will flow towards modernisation of ailing infrastructure and meeting growing energy demand. But the breakdown of financing for technology under the 1.5°C Scenario differs greatly from current plans: USD 24 trillion of planned investments will have to be redirected from fossil fuels to energy transition technologies between now and 2050.

Funding structures in the 1.5°C Scenario are markedly different in terms of capital sources (public and private) and types of capital (equity and debt). In 2019, USD 1.6 trillion in energy assets were financed by private sources, accounting for 80% of total energy sector investment. That share would grow dramatically under the 1.5°C Scenario. The share of debt capital has to increase from 44% in 2019 to 57% in 2050, almost 20% more than under the PES (see Figure S.6). Energy transition technologies should find it increasingly easy to obtain affordable long-term debt financing, while "brown" assets will progressively be avoided by private financiers and therefore forced to rely on equity financing from retained earnings and new equity issues. Capital-intensive, more decentralised projects will influence investors' risk perception, which in turn may need targeted policy and capital market interventions.

Public funding will need to grow almost two-fold to catalyse private finance and ensure just and inclusive unfolding of the energy transition. Public financing plays a crucial role in facilitating the energy transition, as markets alone are not likely to move rapidly enough. In 2019, the public sector provided some USD 450 billion in the form of public equity and lending by development finance institutions. In the 1.5°C Scenario, these investments will grow to some USD 780 billion. Public debt financing will be an important facilitator for other lenders, especially in developing markets with high real or perceived risks. In some instances, this may include grants to reduce the cost of financing. Public funds are also needed to create an enabling environment for the transition and ensure that it occurs fast enough and with optimal socio-economic outcomes.

FIGURE S.6 Total average yearly investment by source and type of financing: 2019, PES and 1.5°C Scenario (2021-2030 and 2031-2050)



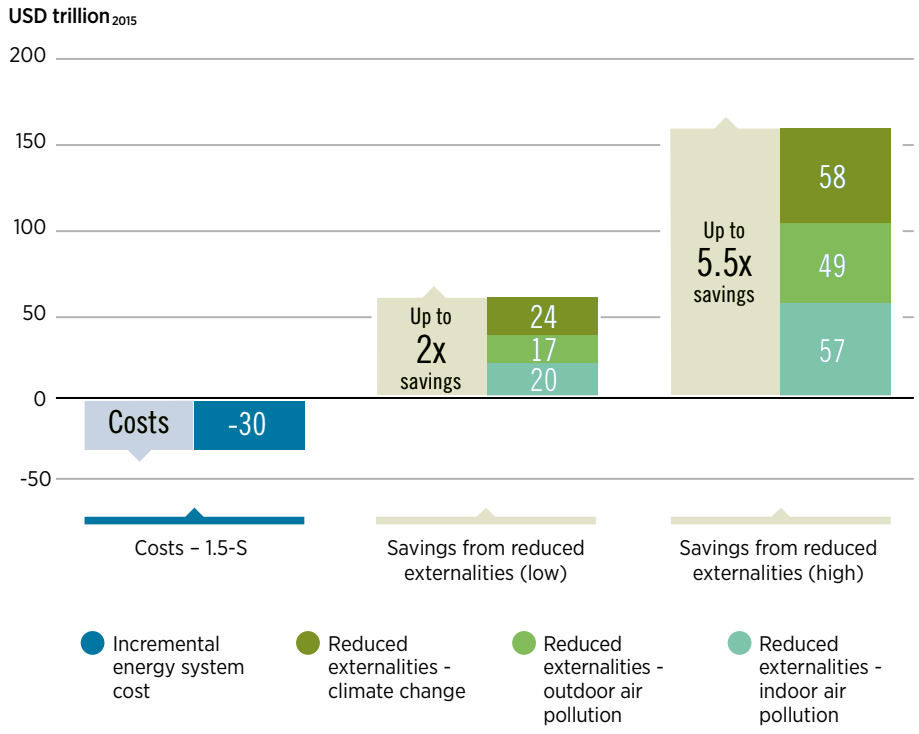
Sources: For 2019 investment: source and type of financing BNEF (2021a), IEA (2020a), IRENA and CPI (2020); for PES and 1.5°C Scenario: IRENA and BCG analysis.

Measures to eliminate market distortions that favour fossil fuels, coupled with incentives for energy transition solutions, will facilitate the necessary changes in funding structures. This will involve phasing out fossil fuel subsidies and changing fiscal systems to reflect the negative environmental, health and social costs of the fossil fuel-based energy system. Monetary and fiscal policies, including carbon pricing policies, will enhance the competitiveness of transition-related solutions. Such interventions should be accompanied by a careful assessment of the social and equity dimensions to ensure that the situation of low-income populations is not worsened but improved.

Socio-economic footprint of the energy transition

Investment in the 1.5°C Scenario will yield a cumulative payback of at least USD 61 trillion by 2050. The overall balance from the energy transition is positive, with benefits greatly exceeding costs. The costs for reducing emissions vary by technology and sector, but the incremental costs are significantly lower than the savings achieved by cutting external costs. IRENA estimates that, under the 1.5°C Scenario, every USD 1 spent on the energy transition should yield benefits from reduced externalities from human health and the environment" after "benefits valued at between USD 2 and USD 5.5. In cumulative terms, the additional USD 30 trillion cost implied by the 1.5°C Scenario over the period to 2050 will result in a payback of between USD 61 and USD 164 trillion.

FIGURE S.7 Cumulative difference between costs and savings of 1.5°C Scenario compared to the PES, 2021-2050



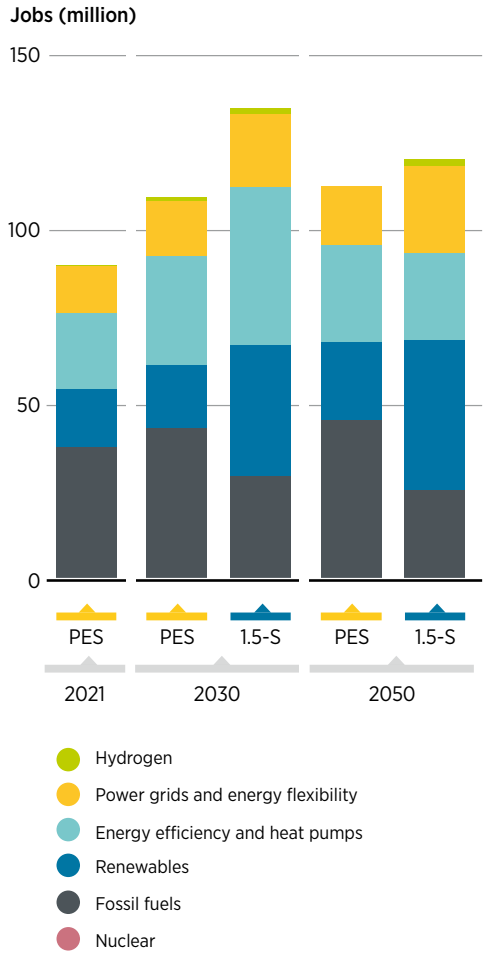
The energy transition goes well beyond technology and brings deep structural changes that will greatly affect economies and societies. IRENA continues to capture an increasingly comprehensive picture of the socio-economic impacts of the energy transition. Results presented in this *Outlook* demonstrate that steps towards a decarbonised energy future will positively affect economic activity, jobs and welfare, provided a holistic policy framework is in place. Within the analysis, countries' existing policies are complemented with climate policies to reach energy transition targets while addressing distributional challenges for just and inclusive outcomes.

The 1.5°C Pathway provides a boost in GDP that is 2.4% greater (on average) than that of the PES over the next decade, aligned with the needs of a post-COVID recovery. Over the transition period to 2050, the average improvement of GDP is estimated at 1.2% over the PES. Additional GDP growth will be spurred by investment across the many dimensions of the energy transition, leading to multiple adjustments between interdependent economic sectors. The reduced demand for fossil fuels leads to lower revenues for mining and fuel refining industries, as well as for governments (because of lower fossil fuel royalties), thus resulting in negative impacts on GDP in some countries. This reality highlights the need for a holistic policy framework that addresses structural changes caused by reduced fossil fuel dependency.

Throughout the transition period, economy-wide employment is 0.9% higher on average under the 1.5°C Scenario than under the PES. One of the main positive impacts on employment comes from investment in energy transition solutions, including renewables, grid enhancement and energy efficiency. Shifting investment from fossil fuels (extraction and power generation) and other sectors towards the energy transition decreases labour demand in fossil fuel and non-energy sectors and along their value chains.

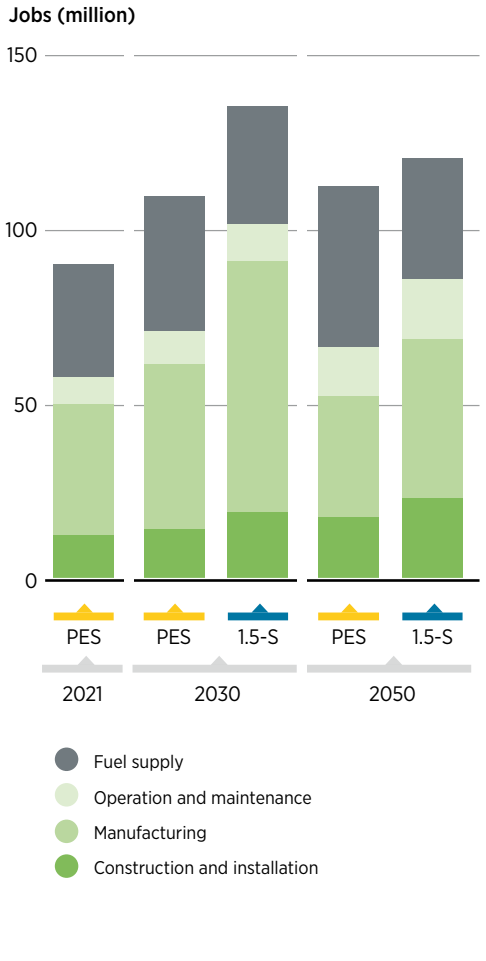
A transformed energy sector will have 122 million jobs in 2050. Qualifications, skills and occupations under the ambitious 1.5°C Scenario are increasingly concentrated in manufacturing, followed by fuel supply. Training for such occupations is relatively easy and offers opportunities for workers from the fossil-fuel industry. The educational requirements for the labour force evolve during the transition, with a continuous increase of the share and number of workers with primary education and a peak of workers with tertiary education by 2030.

FIGURE S.8 Energy sector jobs by technology under the PES and 1.5°C Scenario (million), global results



Based on IRENA's analysis.

FIGURE S.9 Energy sector jobs, by segment of value chain, in the 1.5°C Scenario and PES (excluding vehicles)



Based on IRENA's analysis.

Renewable energy jobs will increase to 43 million in 2050. In the PES, renewable energy jobs increase 9% from 2021 values to reach 18 million jobs by 2030 and 23 million by 2050. By contrast, the 1.5°C Scenario leads to a much larger gain by 2030, with renewables jobs more than tripling to 38 million over the coming decade. Solar photovoltaic (PV) accounts for the largest share, followed by bioenergy, wind and hydropower. Construction, installation and manufacturing boost renewable jobs during the following decade, with operation and maintenance gaining relative weight as the transition advances under the 1.5°C Scenario.

FIGURE S.10 Jobs in renewable energy, by technology, in the 1.5°C Scenario and PES (million)

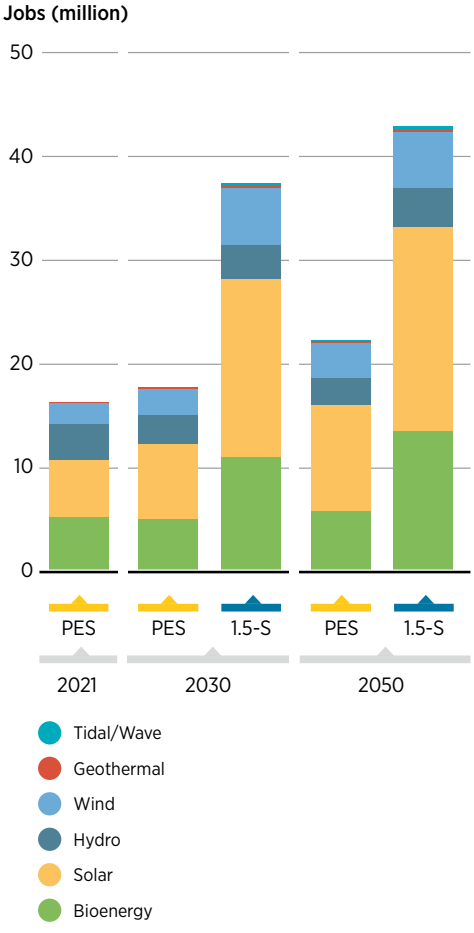
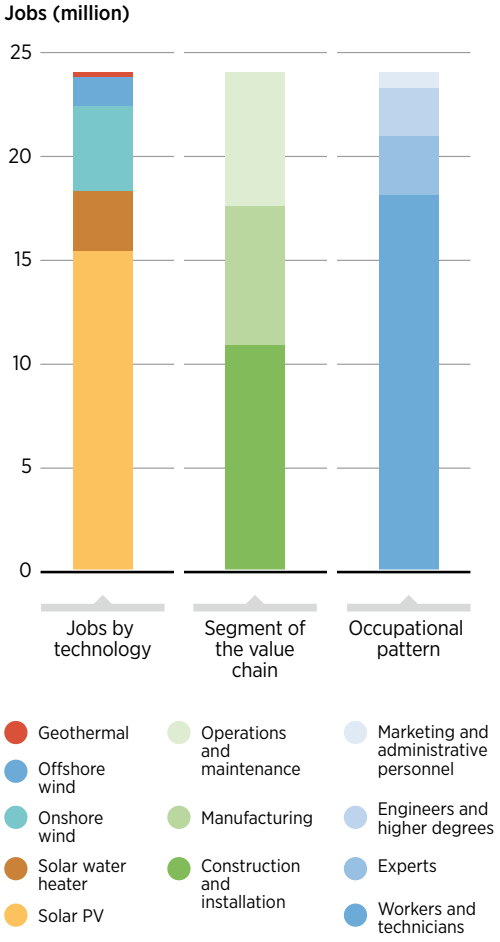


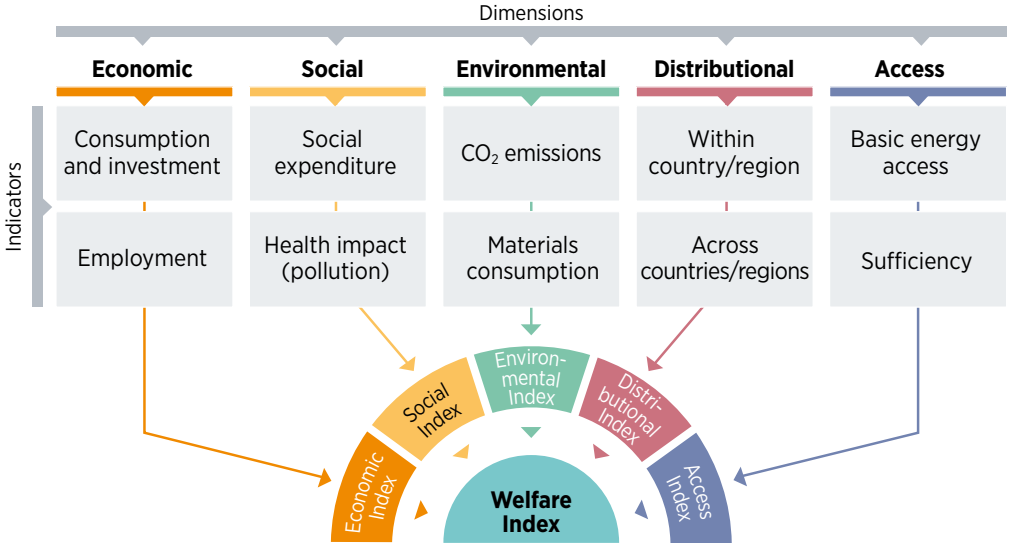
FIGURE S.11 Structure of jobs in the 1.5°C Scenario by 2050 for a subset of renewable technologies by technology, segment of value chain and occupational requirements



Based on IRENA analysis.

IRENA's Energy Transition Welfare Index captures economic, social, environmental, distributional and energy access dimensions. For the first time, the Index reports distributional and energy access dimensions that are often overlooked in other analyses. Measuring the impact of the transition across these dimensions provides a quantitative basis for roadmaps designed to reap the transition's full socio-economic and environmental benefits.

FIGURE S.12 Structure of IRENA's Energy Transition Welfare Index



The 1.5°C Scenario performs better than the PES along all welfare dimensions, yielding an 11% improvement over the PES by 2050.

- The ***economic dimension*** is similar for both scenarios reflecting the energy sector's relatively small share in the overall global economy and labour force.
- The ***environmental dimension*** sees a 30% improvement over PES with significantly lower emissions under the 1.5°C Scenario, although increased materials consumption poses sustainability challenges.
- The ***social dimension*** improves 23% under the 1.5°C Scenario largely due to improved health outcomes from lower outdoor and indoor air pollution. Social expenditures contribute a much smaller role.
- The ***distributional dimension*** improves 37% over PES; however, the index remains low in an absolute sense, indicating potential equity barriers. In fact, both social and distributional dimensions bring down the overall Energy Transition Welfare Index – and these realities deserve more policy attention.
- The ***energy access dimension*** grows 7% under the 1.5°C Scenario compared to PES as universal energy access and sufficiently levels are reached.

Socio-economic impacts vary at the regional and country level. Global aggregates mask important differences in how the energy transition affects regions and countries and how benefits are distributed. What is clear is that the energy transition roadmaps and their resulting socio-economic implications are closely linked with the policy framework, with those links becoming stronger as ambitions align with the 1.5°C Pathway. Governments' involvement in the transition should be accompanied by international co-operation to ensure that the benefits and burdens of the transition are equitably shared.

TABLE S.2 Overview of structural change and just transition policies

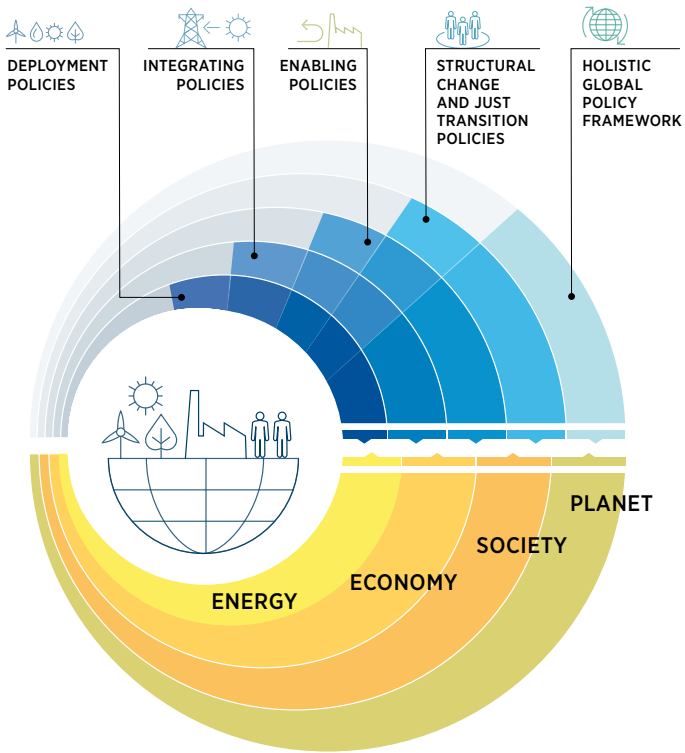
OBJECTIVE	RECOMMENDATIONS
Address potential misalignments in labour markets	Ensuring a just and fair transition will require measures to overcome temporal, geographic and skills-related imbalances.
Develop local value chains	Enhancing and leveraging domestic capabilities requires carefully crafted incentives and rules, business incubation initiatives, supplier-development programmes, support for small and medium enterprises and promotion of key industrial clusters.
Provide education and build capacity	Early exposure to renewable-energy-related topics and careers is vital for sparking young people's interests in pursuing a career in the sector, and also to increase social acceptance by a knowledgeable citizenry.
Support a circular economy	Policies and measures are needed to ensure the sustainability of energy transition-related solutions and their smooth integration in existing ecosystems in terms of sustainability, circular economy principles and reduced environmental impacts.
Support community and citizen engagement	Community energy can play an important role in accelerating renewables deployment while generating local socio-economic benefits and increasing public support for local energy transitions.

A comprehensive policy framework for the energy transition

Policy measures and investments in energy transitions can drive a wider structural shift towards resilient economies and societies. The energy sector must be viewed as an integral part of the broader economy to fully understand the impact of the transition and ensure that it is timely and just. Regions and countries have varied starting points, socio-economic priorities and resources, all of which shape the scope and pace of their energy transition. Energy transitions trigger structural changes that bring benefits as well as challenges, with those challenges appearing in the form of misalignments in finance, labour markets, power systems and the energy sector itself. These misalignments, if not well managed, risk inequitable outcomes and a slowdown in the energy transition. Just and integrated policies – implemented by strong institutions – are imperative to realise the full potential of the energy transition.

International co-operation is an essential piece of the global energy transition. A holistic global policy framework is needed to bring countries together to commit to a just transition that leaves no one behind and strengthens the international flow of finance, capacity and technologies. Climate policies represent a crucial element in such a framework. Other measures should include fiscal policies (such as adequate carbon pricing covering emissions across sectors) and public funding to implement policies to foster deployment, create enabling conditions and ensure a just and stable transition. Elements of the latter imperative include industrial development, education and training, and social protection. The necessary financial resources will not always be available domestically. International co-operation will be needed to provide such support, particularly to the least-developed countries and small island developing states.

FIGURE S.13 Enabling policy framework for a just and inclusive energy transition



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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. An 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**