IRENA
International Renewable Energy Agency

WORLD ENERGY TRANSITIONS OUTLOOK

1.5°C PATHWAY

PREVIEW

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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**

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DISCLAIMER

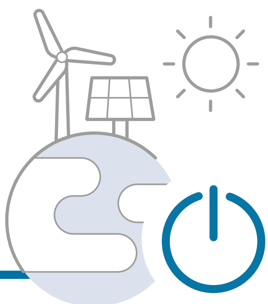
CONTENT

MESSAGE FROM THE **DIRECTOR-GENERAL**

The window of opportunity to achieve the 1.5°C Paris Agreement goal is closing fast. The recent trends show that the gap between where we are and where we should be is not decreasing but widening. We are heading in the wrong direction. The Intergovernmental Panel on Climate Change's (IPCC's) Special Report on Global Warming of 1.5°C released in 2018 clearly indicates that a 45% reduction in global greenhouse gas emissions from 2010 levels is required by 2030.[1] However, emissions have continued to increase, except in 2020, when the COVID-19 pandemic caused a dramatic economic slowdown. Indications are that a rebound is very likely to happen, at least in the short term.

What is at stake is the ability to avoid further irreversible warming with profound economic and humanitarian consequences. The most important variable to measure our efforts is time. The coming nine years will clarify whether we can achieve the speed and scale of deployment necessary for a 45% emission reduction. The highest levels of ambition and effort are required to change course. It will not be easy, but we have no choice. While the path is daunting, several favourable elements can make it achievable.

1 **The energy transition is already taking place, and it is unstoppable.** Great strides have been made in the past decade, with governments and markets – including the financial market – clearly opting for renewable-based energy systems. Over 170 countries have renewables targets, and many have included them in their Nationally Determined Contributions. New capacity addition patterns show that renewables routinely outpace fossil fuels and nuclear combined. A clear vision of a new energy system is emerging, based on renewable technologies and complemented by green hydrogen and modern bioenergy. This new system is technically viable and ready for accelerated and widespread adoption.



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2 **Remarkable advances in renewable technologies, enabled by foresighted policies, have placed them well within economic reach in many countries.** The abundance of renewable potentials worldwide makes them a scalable option. IRENA's analysis shows that solutions for immediate deployment exist to substantially reduce emissions, without the need to wait for new or unproven technologies. For many countries, this translates a technical and economic challenge into a set of investment, regulatory and societal actions. A 1.5°C pathway is not only about what we can do but also what we must not do. It means that all coal plants in the pipeline should be abandoned for more economically and environmentally suitable solutions.

3 **The COVID-19 crisis response offers an unexpected opening to change direction with careful recalibrating of stimulus packages and recovery measures.** The COVID-19 crisis highlighted the cost of tying economies to the fate of fuels prone to price shocks. The energy system, along with the rest of the economy, has been shaken to the core. Amid this, renewables have shown remarkable resilience. Renewable power was a preferred option early on for several reasons, notably its abundance and low operating costs. The crisis was also a test case for renewables-based electricity, debunking myths around the reliability of systems with high shares of solar and wind.

The energy transition can no longer be limited to mitigation efforts or incremental steps. It has to become a transformational effort, a system overhaul, based on the rapid upscaling of available technologies while innovating for the future. The emerging energy system must promote a more inclusive and equitable world, with resilience against economic and environmental shocks. Governments and investors now have the opportunity, and the responsibility, to bring about lasting change.

Francesco La Camera
Director-General, IRENA

ABOUT THIS **PREVIEW**

This study builds on IRENA's REmap (Renewable Energy Roadmap) approach,[2] which has formed the basis for a succession of global, regional, country-level and sector-specific analyses since 2014. REmap is also the foundation of IRENA's socio-economic analyses[3] that capture an increasingly comprehensive picture of the impact of the energy transition on economies and societies. This preview of the *World Energy Transitions Outlook* outlines a more nuanced vision of the transition of the world's energy landscape aligned with the Paris Agreement goals. It shows the pathway to limiting the global temperature rise to 1.5°C and bringing CO_2 emissions closer to net zero by mid-century. This publication presents high-level insights on technology choices, investment needs and socio-economic contexts involved in setting the world on a trajectory towards a sustainable, resilient and inclusive energy future. This preview will be followed by the full report of the *World Energy Transitions Outlook*, which will delve into the factors outlined here in more depth, along with socio-economic impacts of the transition, policy recommendations and financing sources.

Box 1: Scenarios in this outlook

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 (as of 2019), including Nationally Determined Contributions (NDCs) under the Paris Agreement.

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 including all sources of renewable energy, electrification measures and energy efficiency, which can be scaled up at the necessary pace for the 1.5°C goal. The 1.5-S is not limited exclusively to these technologies. It also accounts for innovation and emerging solutions, especially in the coming decades.

1 INTRODUCTION

IRENA's *World Energy Transitions Outlook* provides the contours of an energy pathway and a concise set of actions fully aligned with the findings of the Intergovernmental Panel on Climate Change and the needs of a just, inclusive and orderly transition. This preview – prepared for the Berlin Energy Transition Dialogue in March 2021 – provides highlights from IRENA's latest analysis and outlines immediate priority actions and investments and areas where accelerated improvement is necessary. The analysis also considers transformative technologies such as green hydrogen and sustainable bioenergy, which will play an essential role over the mid and long term.

A combination of technologies is needed to keep us on a 1.5°C climate pathway, in particular:

- Stabilised energy demand through increased energy efficiency and circular economy measures while maintaining economic growth;
- Decarbonised power systems with supply dominated by renewables to meet growing needs;
- Electrification of end-use sectors, with the increased use of electricity in buildings, industry and transport;
- Expanded production and use of green hydrogen, synthetic fuels and feedstocks to pursue indirect electrification;
- Targeted use of sustainably sourced biomass, particularly in place of high-energy-density fuels such as those used in aviation and other transport modes, or in greening gas grids.

↓1.5°C

This preview assesses these options to bring clarity to their scale, timelines and required investments. Furthermore, it explores abatement options for the last share of emissions, which will require a limited deployment of carbon capture and storage (CCS) and carbon dioxide removal (CDR) technologies. Additional focus was placed on the use of Biomass with CCS (BECCS) as a negative emissions option.

Countries and regions are increasingly making ambitious and far-reaching commitments to climate action, with almost 30 already set to achieve net zero in the coming decades. This is creating a new political momentum and fertile ground for an ambitious energy transition pace. With the right decisions, these commitments will be translated into a new energy path. This requires a consistent focus on the technology choices and sequencing that will bring optimal outcomes. Equally important is to avoid becoming side-tracked by seemingly viable solutions that could misdirect valuable resources and efforts in the coming years.

The preview of the *World Energy Transitions Outlook* clarifies these choices to support informed policy and decision making for a 21st-century energy system. Following this preview and aligned with the UN High-Level Dialogue process, IRENA will release the full *World Energy Transitions Outlook*, also outlining a comprehensive socio-economic footprint and accompanying policy measures for the transition, along with financing sources and market insights.

2 ENERGY TRANSITION **FOR 1.5°C**

Holding the line at 1.5°C means reaching net zero by 2050 and ensuring a rapid decline in emissions beginning now. Countries around the world need to accelerate their efforts toward the energy transition without delay.

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 carbon dioxide (CO_2) emissions increased 1.3% annually, on average, over the period 2014 to 2019.[4] While last year, 2020, was an outlier due to the pandemic, as emissions declined 7%,[5] a rebound looks very likely, at least in the short term.

Meanwhile, in the last few years the energy sector has begun to change in promising ways, enabled by supporting policy and innovations in technologies and systems. Renewable power technologies are dominating the global market for new generation capacity. Following increasing renewables deployments in 2019 (around 176 gigawatts [GW] added globally[6]), indications are that 2020 was a record year for wind and solar photovoltaic (PV) markets, with current market forecasts suggesting that about 71 GW[7] and 115 GW[8] are expected to be added, respectively. New records for low-priced solar PV were achieved (less than 2 US cents per kilowatt hour [kWh]). The electrification of transport is showing signs of disruptive transition – the global sales of electric cars grew by 43% compared to 2019, to reach 3.2 million units, accounting for 4.2% of global new car sales.[9] Key enabling technologies, such as battery packs and cells for mobility applications, saw rapid cost reductions from an average USD 181/kWh in 2018 to USD 137/kWh in 2020[10] (the lowest-cost applications were under USD 100/kWh).

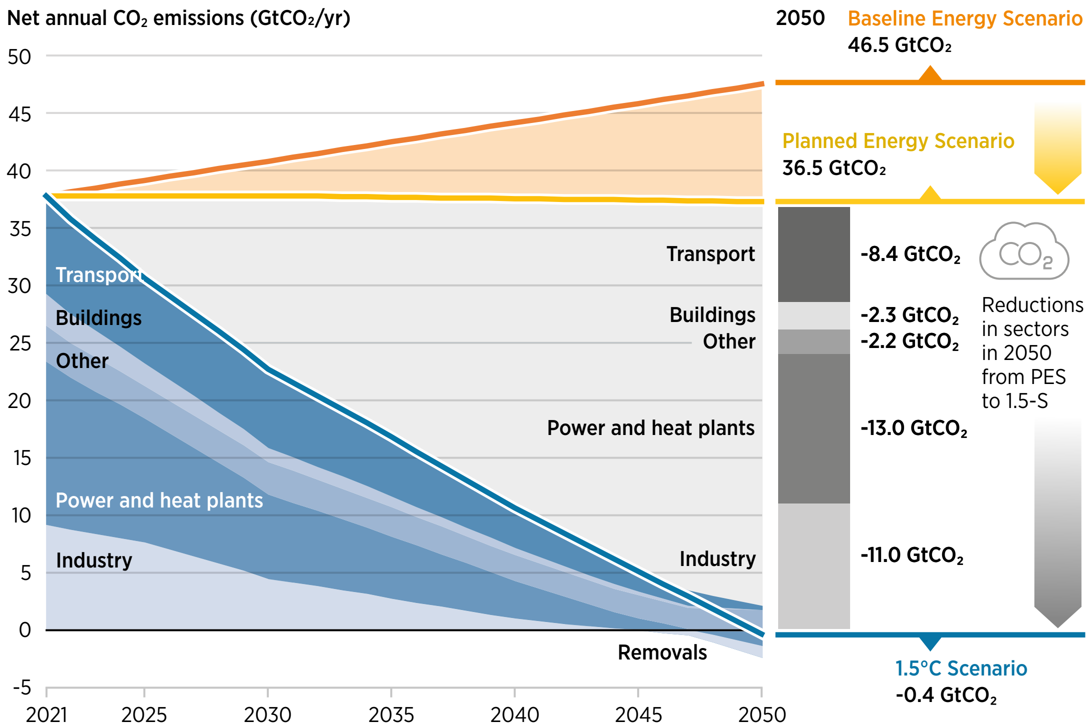
However, the speed of the transition is far from what is needed to be in line with the Paris Agreement. Policies in place* will yield only global emissions stabilisation with a slight drop towards 2050 (as in the Planned Energy Scenario [PES]). However, if these policies are not fully implemented, emissions could potentially rise 27% over the coming three decades (as indicated in the Baseline Energy Scenario [BES] in Figure 1). Overall, the pace of future projections indicated in the Planned Energy Scenario falls far short of what is needed for a 1.5°C pathway. The time dimension is crucial, and a radical shift is required, starting today, based on readily available renewable energy and energy efficiency technologies that can be scaled up now. This Outlook outlines what is required for such a shift and presents an energy pathway that is consistent with limiting global temperature rises to 1.5°C – a pathway IRENA calls the 1.5°C Scenario (1.5-S).

* Based on governments' current energy plans and other planned targets and policies, including the first round of Nationally Determined Contributions under the Paris Agreement (as of 2019).

Aligned with the Intergovernmental Panel on Climate Change's special report on global warming of 1.5°C,[1] the IRENA analysis starts with the goal of reducing global CO_2 emissions following a steep and continuous downward trajectory from now on and reaching net zero by 2050. The energy sector is responsible for around 80% of anthropogenic CO_2 emissions and has a central role in delivering the decarbonisation required. To reach net zero by 2050, CO_2 emissions must decline 3.5% year-on-year, on average. The 1.5°C Scenario shows that this is achievable but extremely challenging, requiring urgent action on multiple fronts.

FIGURE 1 **For the 1.5°C climate target, global CO_2 emissions need to drop to net zero by 2050**

Annual net CO_2 emissions 2021–2050 – $GtCO_2$/yr, Baseline Energy Scenario (BES), Planned Energy Scenario (PES) and 1.5°C Scenario (1.5-S)



Note: The blue shaded areas in the figure represent the remaining net CO_2 emissions in corresponding sectors in the 1.5-S and the grey area represents the reductions in CO_2 emissions in the 1.5-S compared to the PES. Industry includes energy and process related CO_2 emissions. International bunkers are included in transport emissions. Others include emissions from non-energy uses and other sectors such as agriculture, forestry etc. Emissions in industry and power and heat generation plants include CO_2 emissions captured by carbon capture, BECCS and other carbon removal measures. As a result, towards 2050 these two sectors become net negative, i.e., the CO_2 captured more than compensates remaining CO_2 emissions in those sectors. Overall, the net CO_2 emissions in the 1.5-S in 2050 would reach -0.4 Gt.

$GtCO_2$/yr = gigatonnes of carbon dioxide per year; PES = Planned Energy Scenario.

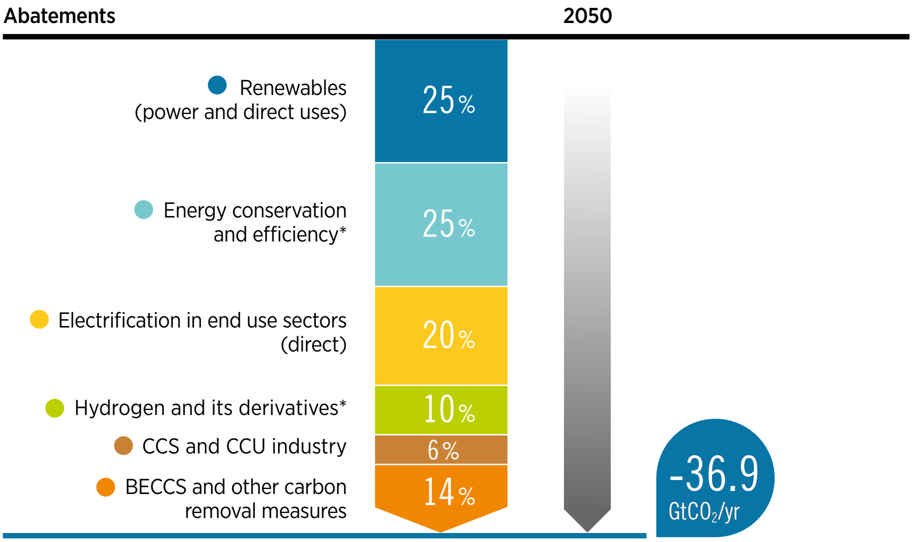
In the Planned Energy Scenario annual emissions reach 36.5 gigatonnes of carbon dioxide ($GtCO_2$) in 2050. For the 1.5°C Scenario, emissions need to drop to net zero. All sectors need to reach almost net zero. Further efforts in sectors such as power, heat and industry are needed, with negative emissions delivering the necessary additional carbon reductions.

The *World Energy Transitions Outlook* identifies six main components of the CO_2 emissions abatement:

1. Renewables
2. Energy conservation and efficiency
3. Electrification in the end-use sectors
4. Hydrogen and its derivatives
5. CCS and CCU
6. BECCS and other carbon removal measures

FIGURE 2 Six components of the energy transition strategy

CO_2 emissions abatement options between the 1.5°C Scenario and PES



Note: The abatement estimates in the figure between the PES and 1.5-S include energy (incl. bunkers) and process-related CO_2 emissions along with emissions from non-energy use. Renewables include renewable power generation sources and direct use of renewable heat and biomass. Energy efficiency includes measures related to reduced demand and efficiency improvements. Structural changes (e.g. relocation of steel production with direct reduced iron) and circular economy practices are part of energy efficiency. Electrification includes direct use of clean electricity in transport and heat applications. Hydrogen and its derivatives include use of hydrogen and synthetic fuels and feedstocks. CCS describes carbon capture and storage from point-source fossil-fuel-based and other emitting processes mainly in industry. BECCS and other carbon removal measures include bioenergy coupled with CCS (BECCS) in electricity and heat generation, and in industry and other measures in industry.

BECCS = bioenergy with CCS; CCS = carbon capture and storage; CCU = carbon capture and utilisation; $GtCO_2$ = gigatonnes of carbon dioxide.

Renewable energy plays a key role in the decarbonisation effort. Over 90% of the solutions in 2050 involve renewable energy through direct supply, electrification, energy efficiency, green hydrogen and BECCS. Fossil-based CCS has a limited role to play, and the contribution of nuclear remains at the same levels as today.

The portfolio of technologies needed to decarbonise the world energy system mostly exists today, but innovative solutions are considered as well.

IRENA's 1.5°C Scenario considers today's proven technologies as well as innovative technologies that are still under development but which that could play a significant role by 2050. For example, in the case of renewable power generation technologies, offshore renewable energy such as floating offshore wind and emerging ocean energy technologies could support sustainable long-term development and drive a vibrant blue economy. On the end use side, innovation extends from electrified transport modes (*e.g.* long range electric trucks) and e-fuels (*e.g.* green hydrogen-based ammonia and methanol) to alternative production processes in manufacturing industry (*e.g.* direct reduced iron production using green hydrogen) as well as green buildings (*e.g.* smart buildings for energy management along with net zero buildings). Speculative solutions still at an early stage of development have been excluded.

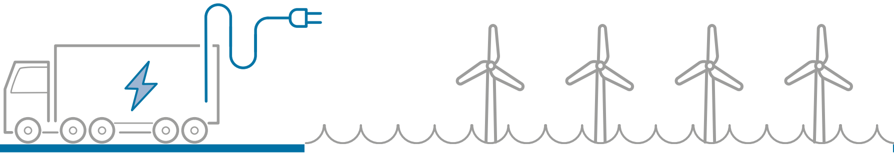
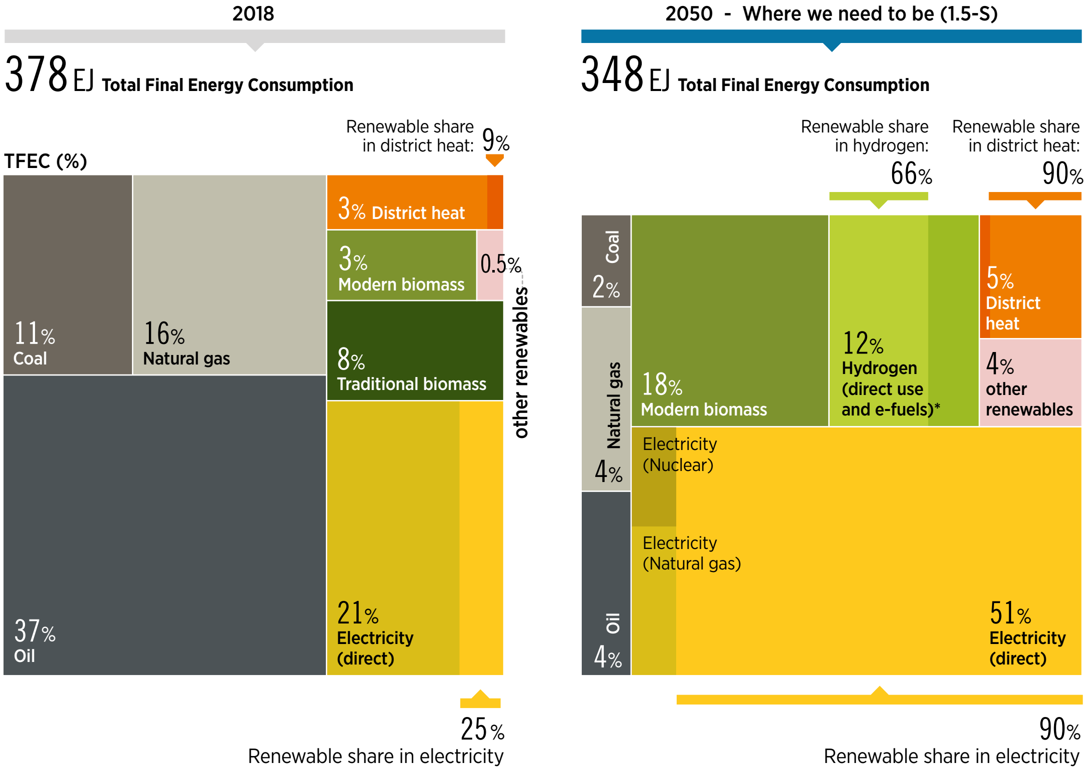


FIGURE 3 Electricity becomes the main energy carrier in energy consumption by 2050

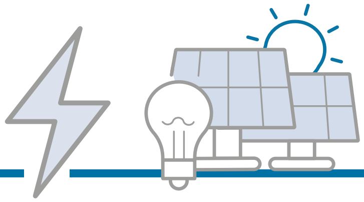
Breakdown of total final energy consumption (TFEC) by energy carrier in 2018 and 2050 (EJ) in the 1.5°C Scenario (1.5-S)



Note: The figures above include only energy consumption, excluding non-energy uses. For electricity use, 25% in 2018 and 90% in 2050 is sourced from renewable sources; for district heating, these shares are 9% and 90%, respectively; for hydrogen (direct use and e-fuels), the RE shares (i.e., green hydrogen) would reach 66% 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 all sources of generation: renewable, nuclear and fossil fuel based. DH = district heat; EJ = exajoules; RE = renewable energy.

By 2050, electricity would be the main energy carrier with over 50% (direct) share of total final energy use – up from 21% today. By 2050, 90% of total electricity needs would be supplied by renewables followed by 6% from natural gas and the remaining from nuclear.

Renewables, electrification and energy efficiency are the main pillars of the energy transition.



The most important synergy in the global energy transition is the combination of the increasing use of low-cost renewable power technologies and the wider adoption of electricity to power end-use applications in transport and heat. Electrification allows for the use of carbon-free electricity in place of fossil fuels in end-use applications, and significantly improves the overall efficiency of the energy service supply. Electric vehicles, for instance, are more efficient than internal combustion engines. Hydropower generation, as well, is more efficient than natural gas generation. This is important as reductions in energy intensity need to be accelerated.

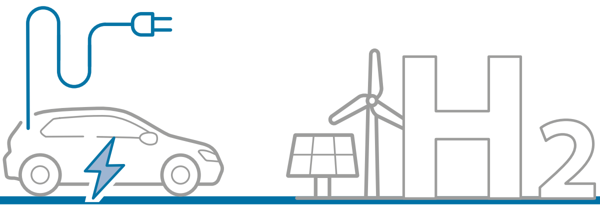
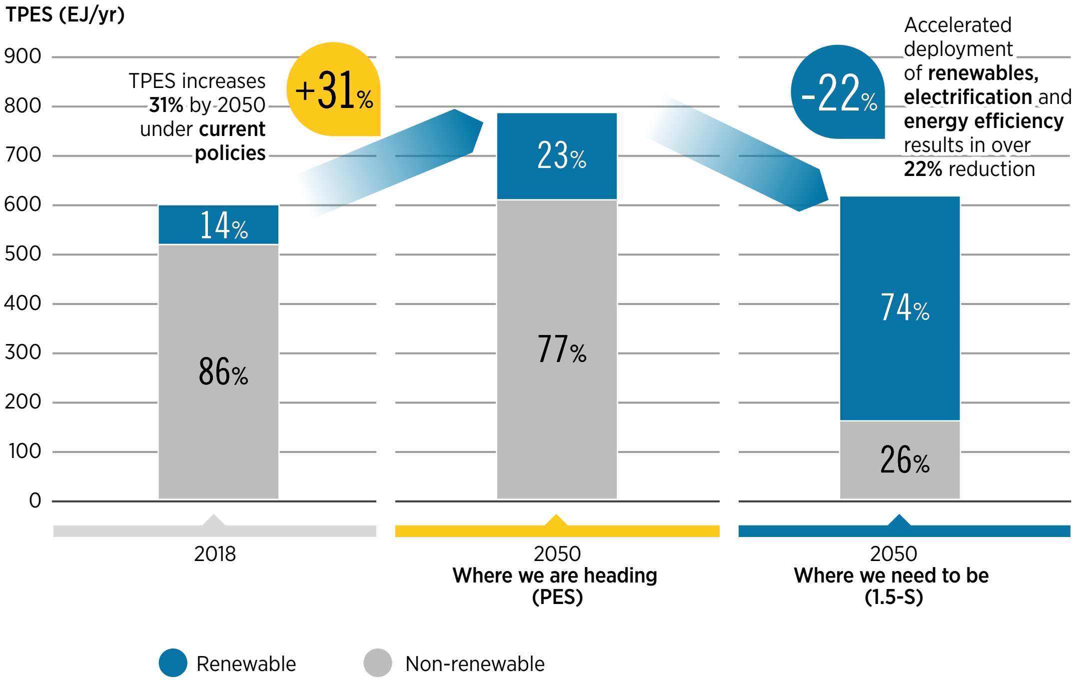


FIGURE 4 **The global energy supply must become more efficient and more renewable**

TPES, renewable and non-renewable share for 2018, PES and the 1.5°C Scenario (1.5-S) (EJ/yr)



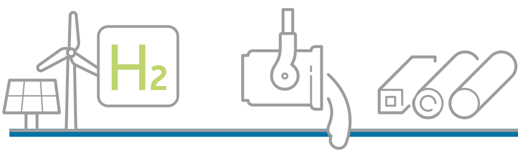
Note: Data include international bunkers and non-energy use of fuels for the production of chemicals and polymers. 1.5-S = 1.5°C Scenario; EJ/yr = exajoules per year PES = Planned Energy Scenario; TPES = total primary energy supply.

The share of renewable energy in primary supply must grow from 14% in 2018 to 74% in 2050 in the 1.5°C Scenario. This requires an eight-fold increase in annual growth rate, from 0.25 percentage points (pp) in recent years to 2 pp. Primary supply stabilises during this period as a consequence of increased energy efficiency and the growth of renewables.

1.5°C

A circular economy will play an increasingly important role in coming decades, contributing to reductions in energy consumption and increases in the efficiency of resource use, alongside improvements in material efficiency in industry due to innovations. Advanced digital and communication technologies with enhanced connectivity make it possible to optimise the transport of heavy goods (*e.g.* as efficiency enhancements in traffic control reduce the overall energy consumed by freight). Technology shifts can also lead to the relocation of industrial processes, for instance, the shift from traditional carbon and energy-intensive steel production methods to green steel production methods with green hydrogen. Electric arc furnaces could enable a wider relocation of the iron and steel sector to places where relatively low-cost and abundant renewable electricity sources are available. Such shifts could also have geopolitical and global economic implications.[11]

In the 1.5°C Scenario, the rate of energy intensity improvement needs to increase to 3% per year from 1.2% in 2019.[12] Electrification of end-use sectors utilising renewable power will play a significant role in the transition. In 2050, renewable energy (including renewable fuels and biomass-based carbon removal technologies), electrification and energy efficiency together offer over 90% of the mitigation measures needed to reduce CO_2 emissions in the 1.5°C Scenario.



RAMPING UP ELECTRICITY USE

Electricity generation must expand three-fold by 2050, with renewables providing 90% of the total supply.

In the 1.5°C Scenario, rapid electrification of end-use applications along with the rise of green hydrogen production drive increased power demand. By 2050, power generation triples compared to today's level, and renewables supply 90% of total electricity by 2050, up from 25% in 2018. Natural gas* (around 6%) and nuclear (around 4%) constitute the remainder. Wind and solar PV dominates the power generation mix, supplying 63% of total electricity needs by 2050; other mature renewable technologies (*e.g.* hydro, bio-energy, geothermal and concentrated solar power) and emerging technologies (*e.g.* ocean energy) also play important roles to decarbonise the world's electricity supply. This rise is being accelerated by declining costs: three-quarters of onshore wind and 40% of utility-scale solar PV commissioned in 2019 will produce during their lifetime electricity cheaper than any fossil-fuel alternatives, while three-quarters to four-fifths of the onshore wind and utility-scale solar PV commissioned in 2020 from auction or tenders had prices lower than the cheapest new fossil fuel–fired option.[13]

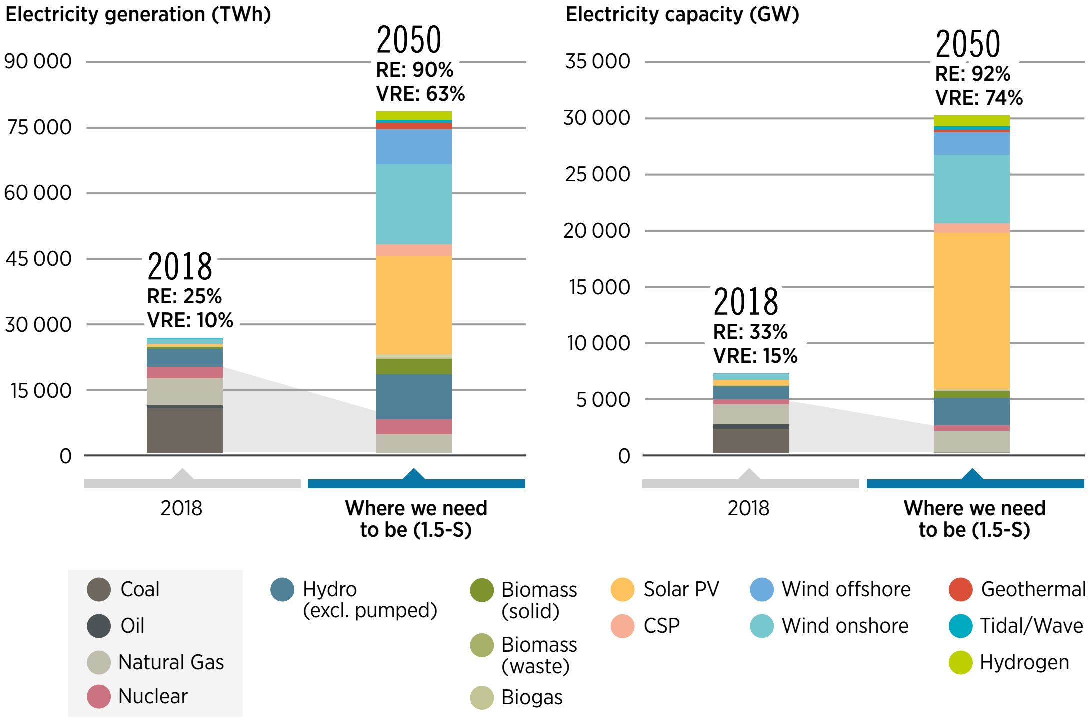
Renewable power installed generation capacity will need to expand from over 2 500 GW today[14] to over 27 700 GW in 2050, more than a ten-fold increase. In annual terms, this requires more than 840 GW of new renewable capacity additions every year, up from around 200 GW added in recent years. Solar PV and wind (onshore and offshore) would lead the way; solar PV power installed capacity would reach over 14 000 GW and wind (onshore and offshore) over 8 100 GW by 2050. Hydropower, biomass, geothermal, concentrated solar power and ocean technologies account for the remaining renewable energy expansion.

Solar thermal, geothermal and bioenergy will be needed to provide heat in industrial processes, cooking and space and water heating in buildings, and fuels for transport. In the 1.5°C Scenario the direct use of renewable energy would need to grow to 77 exajoules (EJ) in 2050 compared to 44 EJ in 2018. Bioenergy makes up a large share of renewable energy use today and will remain a significant source of fuel, both in industry and transport. In the 1.5°C Scenario, the share of final energy met with modern forms of bioenergy increases to 17% in 2050 from around 1.5% today. Priorities for bioenergy will include the production of advanced biofuels for the aviation and shipping sectors, the production and use of renewable fuels and feedstock for the chemical industry, and some use for heating in specific industry sub-sectors. In addition, BECCS will be used in power and heat production and some industrial processes (*e.g.* cement production). IRENA's analysis finds that the level of primary biomass can be harvested sustainably without causing deforestation or other negative land-use changes.[15] However, robust frameworks for regulation, certification and monitoring need to be put in place globally to ensure that biomass supply is environmentally, socially and economically sustainable.

* In the power sector, natural gas would have a role in managing demand fluctuations and providing operational reserves.

FIGURE 5 Renewables will dominate the power generation mix

Electricity generation and capacity by source, 2018, 2050 (TWh/yr and GW/yr) in the 1.5°C Scenario



Note: 1.5-S = 1.5°C Scenario; CSP = concentrated solar power; GW/yr = gigawatts per year; PES = Planned Energy Scenario; PV = photovoltaic; RE = renewable energy; TWh/yr = terawatt hours per year; VRE = variable renewable energy.

Electricity generation grows three-fold from 26 380 terawatt hours (TWh) in 2018 to close to 78 700 TWh in 2050. The share of renewables would grow to 90% in 2050 from 25% in 2018. Following a sharp decrease in coal generation over the current decade, by 2040 coal generation would be a quarter of today's level and eventually would be phased out by 2050. The remaining 10% of total power generation in 2050 would be supplied by natural gas (around 6%) and nuclear (around 4%). Notably, variable renewable sources like wind and solar would grow to 63% of all generation in 2050, compared to 7% in 2018.

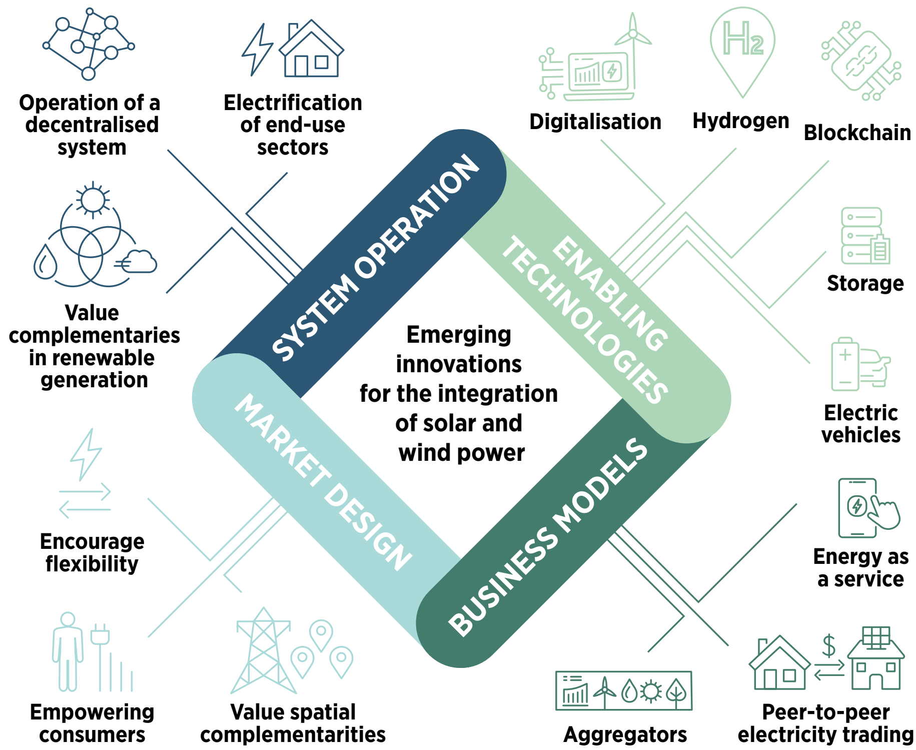
Power systems will need to become much more flexible as the variable renewable energy (VRE) share on average would reach 63% of global power generation.

Flexibility in power systems is a key enabler for integrating high shares of VRE – the backbone of the electricity system of the future. By 2030, the VRE share in total power generation would reach 42%. By 2050, 73% of the installed capacity and 63% of all power generation would come from variable resources (solar PV and wind), up from 15% of the installed capacity and 7% of power generation globally today. Such a level is manageable with current technologies leveraged by further innovations.

There are several best practices in terms of VRE integration from countries around the world. For example, in 2019, the share of VRE in the power generation mix in Denmark was over 50% (47% wind and 3% solar PV);[16] it was over 40% in Lithuania and 34% in Germany (23% wind and 11% solar PV).[17] Systemic innovations are needed that go beyond enabling technologies to integrate innovations in business models, markets and regulations, and system operations to unlock the flexibility of the power system and integrate rising shares of VRE. IRENA has identified 30 flexibility options that can be combined into comprehensive solutions, taking into account the national and regional power system specifics.[18, 19] Moreover, IRENA has been analysing how power system organisational structures (including markets) can be redesigned to foster and support renewable-based energy systems.[20] As more countries adopt ambitious policy targets of very high or 100% renewable power systems, adopting such a systemic approach to innovation will become more important.

The future smart power system, largely based on variable renewables such as solar PV and wind, will require significant investments in power grids and flexibility measures (*e.g.* storage) in the order of USD 730 billion per year over the period to 2050, nearly tripling from USD 275 billion in 2019.[21]

FIGURE 6 **Emerging innovations for the integration of variable renewable energy sources**
Enabling technologies, market design, business models and system operation



Based on IRENA (2019), Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables, International Renewable Energy Agency, Abu Dhabi.

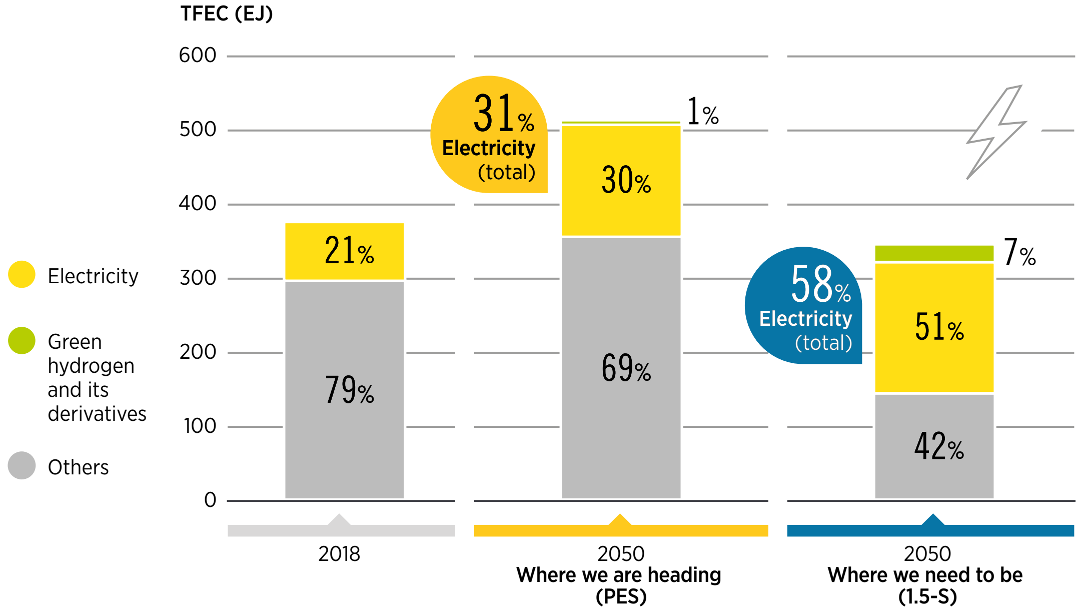
IRENA has identified 30 innovations for the integration of wind and solar PV in power systems, clustered in four dimensions. Innovations across two or more dimensions need to be combined to form an innovative solution. Since there is no "one-size-fits-all" solution, these need to be tailored to the specific power system characteristics of each country.

Electricity will be a key energy carrier, exceeding 50% of final energy use by 2050.

By 2050, electricity will become by far the most important energy carrier. The direct electrification share in final energy consumption (which includes direct use of electricity but excludes indirect uses such as e-fuels) would reach 30% by 2030 and exceed 50% by 2050, up from just above 21% today. The use of green hydrogen and green-hydrogen-based carriers, such as ammonia and methanol, as fuels, would reach almost 2% in 2030 and 7% in 2050 from negligible levels today. In total, direct and indirect electrification would reach 58% of final demand.

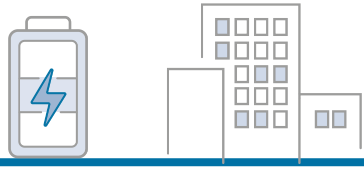
FIGURE 7 Electricity is the central energy carrier in future energy systems

TFEC split by direct electricity and the use of green hydrogen and its derivative fuels, in 2018, PES/2050 and 1.5-S/2050 (EJ/yr)



Note: "7%" in 2050 in the 1.5°C Scenario (1.5-S) corresponds to green hydrogen and its derivatives. In addition, around 11 EJ of green hydrogen would be needed for non-energy uses in 2050 (1.5-S), which is not represented in this figure.

EJ = exajoules; PES = Planned Energy Scenario.



The buildings sector would see the highest direct electrification rates, reaching 73% compared to 32% today. A rise would also be observed in the industry sector, where the direct electrification rate would be 35% by 2050, up from 26% today (including indirect electrification, the rate of electrification would approach 40% by 2050). For decarbonising some heat applications, the total number of heat pumps would rise by close to nine-fold, exceeding 180 million by 2030 and close to 400 million by 2050 compared to around 20 million installed today.

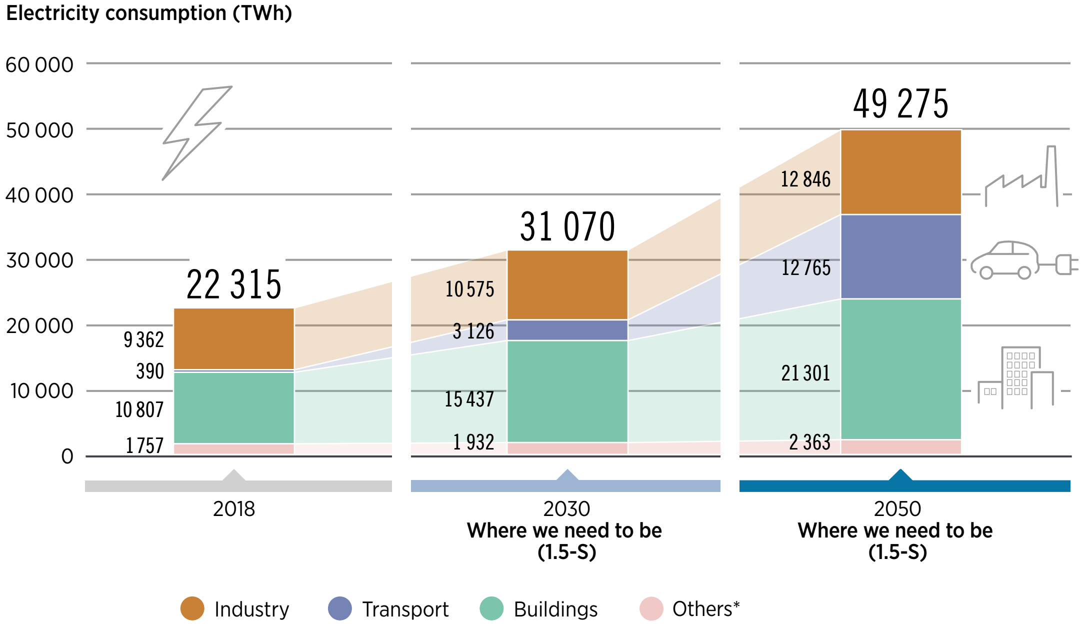
Transport would see the most accelerated electrification in the coming decades with the share of electricity reaching 49% in 2050, up from just 1% today. The stock of electric cars would rise from 10 million today to over 380 million by 2030 and 1780 million by 2050; the stock of electric trucks would rise to 28 million by 2050. Electric vehicles would account for more than 80% of all road transport activity by 2050 (88% of the light-duty vehicles stock and 70% of heavy-duty vehicles).

This massive electrification in transport will be due to technological progress – markedly the evolution of batteries and battery production processes – that has greatly improved the economic case for electric vehicles in recent years and it is quickly expanding the scope of application to a broader set of road vehicle segments and types of services. If the ongoing cost reduction trends can be sustained, by 2050, the bulk of global road transport services could be delivered cost-effectively with electric technologies.

Electricity dominates final energy consumption either directly or indirectly, in the form of hydrogen and other e-fuels such as e-ammonia and e-methanol.
Around 58% of final energy consumption in 2050 is electricity (direct), green hydrogen and its derivatives.

FIGURE 8 **Electricity consumption more than doubles by 2050**

Electricity consumption by end-use sector, 2018, 2030 and 2050 (TWh/yr) in the 1.5°C Scenario



Note: Electricity use for green hydrogen is not included in the figure. By 2050, close to 21 000 TWh of electricity would be needed for green hydrogen production.

*Others also includes electricity consumption by CCS.

1.5-S = 1.5°C Scenario; TWh = terawatt hours.

Electricity demand grows over two-fold in between 2018 and 2050. The use of electricity in industry and buildings doubles. In transport it grows from nearly zero to over 12 700 TWh.

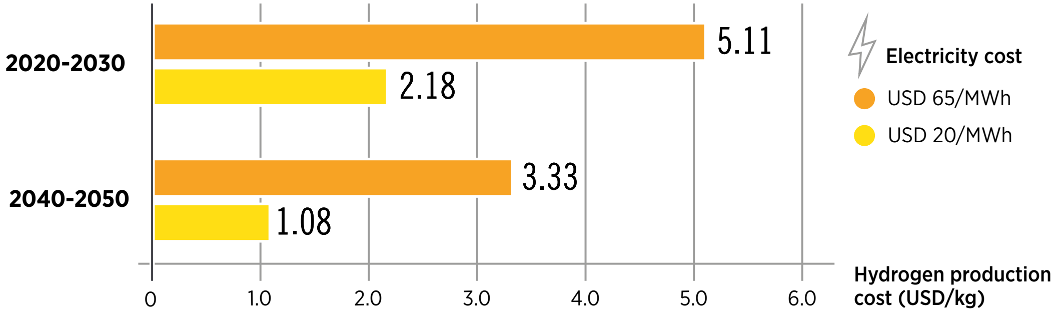
SYSTEM ENHANCEMENT WITH GREEN HYDROGEN AND BIOENERGY

Hydrogen and its derivatives will account for 12% of final energy use by 2050.

By 2050, 30% of electricity use will be dedicated to green hydrogen production and hydrogen and its derivatives such as e-ammonia and e-methanol. Hydrogen and its derivatives together will account for around 12% of total final energy use. To produce this, almost 5 000 GW of hydrogen electrolyser capacity will be needed by 2050, up from just 0.3 GW today.

FIGURE 9 In the next decade the cost of green hydrogen will continue to fall

Hydrogen production cost



Note: A combination of cost reductions in electricity and electrolysers, combined with increased efficiency and operating lifetime, can deliver 80% reduction in green hydrogen cost.

Based on IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5°C Climate Goal, International Renewable Energy Agency, Abu Dhabi.

Green hydrogen can be produced at costs competitive with blue hydrogen by 2030, using low-cost renewable electricity, *i.e.*, around USD 20/megawatt hour (MWh). If rapid scale-up occurs in the next decade, the cost of green hydrogen will continue to fall below USD 1.5/kilogramme (kg).

Hydrogen will offer a solution to industry and transport needs that are hard to meet through direct electrification, mitigating close to 12% and 26% of CO_2 emissions, respectively, in the 1.5°C Scenario compared to the PES. Today, around 120 metric tonnes (Mt) (14 EJ) of hydrogen are produced annually but almost all of this comes from fossil fuels or from electricity generated by fossil fuels, with a high carbon footprint – less than 1% is green hydrogen. As electrolyser costs fall, combined with further reductions in renewable electricity costs, green hydrogen will be less expensive than the estimated cost of blue hydrogen in many locations within the next 5 to 15 years.[22] In the 1.5°C Scenario, by 2050, there will be a demand for 613 Mt (74 EJ) of hydrogen, two-thirds of which will be green hydrogen. The electricity demand to produce hydrogen will reach close to 21 000 TWh by 2050, almost the level of global electricity consumption today. This requires significant scale-up of electrolysers' manufacturing and deployment. Around 160 GW of electrolysers need to be installed annually on average to 2050. The installation rate will start growing from a few gigawatts added per annum in the coming years and eventually ramp up from 2030 onwards, exceeding 400 GW per annum by 2050.

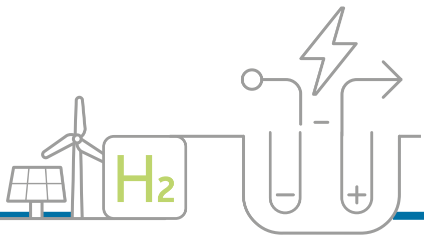
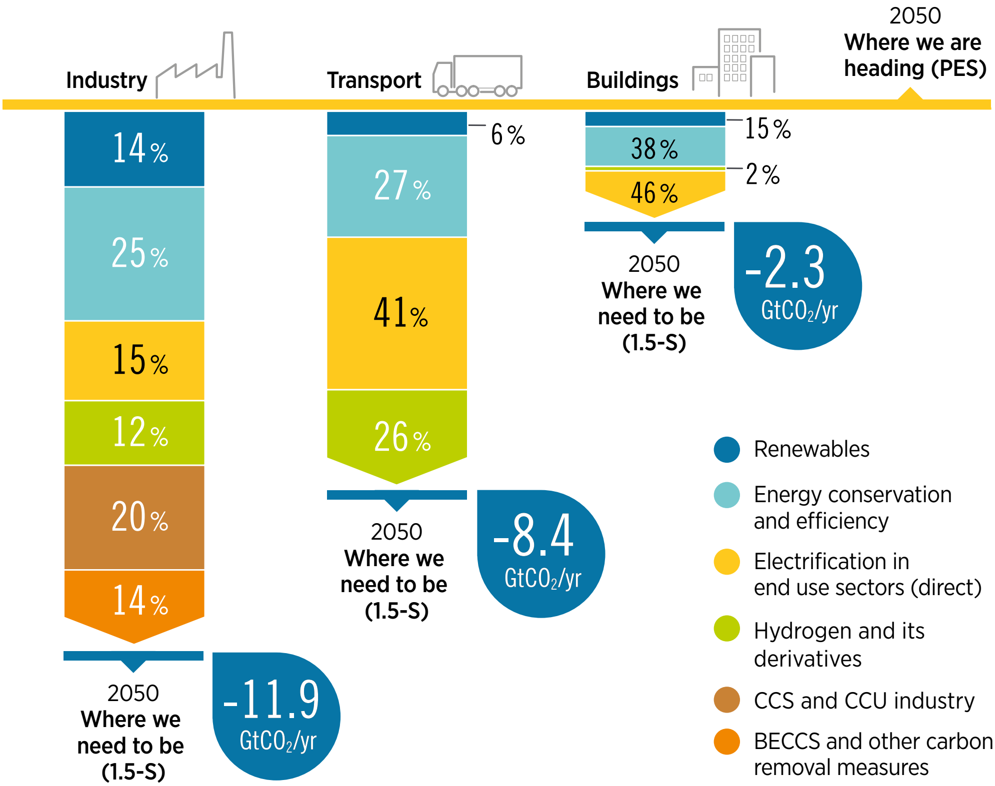


FIGURE 10 Electrification and green hydrogen offer a solution for end-use sectors

CO_2 emissions abatement options between the 1.5°C Scenario and PES in industry, transport and buildings sectors.

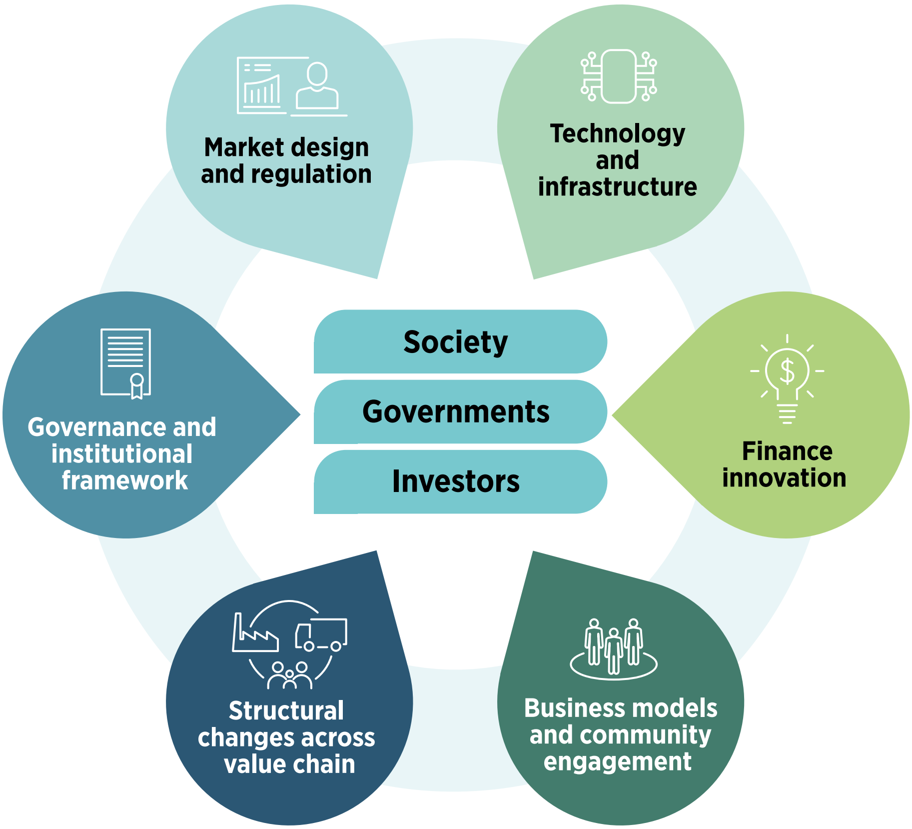


Note: Industry includes emissions from energy, process and non-energy uses. International bunkers are included in transport emissions. Renewables include direct use of renewables such as biomass, solar thermal and geothermal. Energy efficiency includes measures related to reduced demand and efficiency improvements. Structural changes (e.g. relocation of steel production with direct reduced iron) and circular economy practices are part of energy efficiency. Electrification includes direct use of clean electricity. Hydrogen includes indirect use of clean electricity via synthetic fuels and feedstocks (e.g. hydrogen and its derivates). CCS describes carbon capture and storage from point-source fossil-fuel-based and other emitting processes mainly in industry and for blue hydrogen production. BECCS and other carbon removal measures include bioenergy coupled with CCS (BECCS) and other measures such as reforestation and other measures in industry.

$GtCO_2$ = gigatonnes of carbon dioxide;

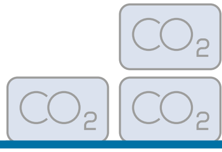
In transport, 67% of emission reductions come from electrification (direct) and hydrogen. In industry, hydrogen and electricity combined contribute 27% of mitigation needs. In buildings, the key solution is electrification (direct and indirect), contributing close to half of the reduction needed, followed by energy efficiency.

FIGURE 11 Integrated innovation for the decarbonisation of the global energy system
Innovation across various dimensions of the energy sector.



Innovation will help drive the energy transition process and decarbonise the energy sector. An integrated innovation approach across different dimensions is needed. As reducing the cost of low-carbon technologies is an overriding priority for innovation, a suite of emerging technology solutions will significantly shape the energy sector's decarbonisation. Driven by innovation and economies of scale, renewable power generation sources are economically attractive. Special attention would be needed for the expansion of emerging technologies such as green hydrogen.

CO_2 removal technologies, CCS, and related measures will be required for the remaining energy and process-related emissions.



Some emissions will exist by 2050 from the remaining fossil fuel use and from some industrial processes. There is thus a need for both CCS technologies that reduce emissions released to the atmosphere and for CO_2 removal measures and technologies that, combined with long-term storage, can remove CO_2 from the atmosphere, resulting in negative emissions. CO_2 removal measures and technologies include reforestation and BECCS* and also, potentially, direct CCS and some other approaches that are currently experimental.

The bioenergy component of BECCS concerns applications whereby CO_2 is produced as flue gas. These include biomass combustion, biomass fermentation or biomass gasification/pyrolysis. The CO_2 produced from biomass is considered neutral to the atmosphere if the source of biomass is continually renewed as the biomass is harvested, for instance, in crop and forest cultivation. Because a crop or forest absorbs CO_2 from the atmosphere as it grows and the CO_2 emitted during combustion ends up back in the atmosphere, the overall carbon balance becomes neutral.

The advantage of BECCS over non-BECCS applications is that the overall balance of CO_2 emissions becomes in fact negative. The biomass absorbs carbon from the atmosphere as it grows and the CCS plant prevents this carbon from going back to the atmosphere during biomass final use, storing it below ground. The overall result is that CO_2 is effectively being removed from the atmosphere through biomass growth and stored somewhere else.

* BECCS stands for bioenergy with carbon capture and storage which means installing a carbon capture and storage (CCS) plant to capture carbon dioxide (CO_2) that is produced from a bioenergy application. In a nutshell, there are two components to this technology: CCS and the bioenergy. The CCS component of BECCS is not different from non-BECCS applications of CCS. It is a technology that captures CO_2 from a gaseous stream, for instance, from the combustion gases of a power plant or a cement kiln. CCS plants involve mainly four steps. One might contain some form of pre-cleaning of the gaseous stream from where CO_2 will be captured to ensure that the stream is free from other gases that may hamper the operation of the following stages of the process. The next step is the capture of CO_2, i.e., some technology that will separate the CO_2 from the gaseous stream and produce a nearly pure CO_2 stream. Next, there is the need to transport this CO_2 stream to the storage site and finally the CO_2 is injected at the storage site for permanent storage. Most storage involves some type of geological reservoir that might be located on land or in the ocean. Gas compression is usually needed in all of the steps of CCS. It is certainly important at the transport and injection stages and represents an important part of the energy demand of the whole process.

↓1.5°C

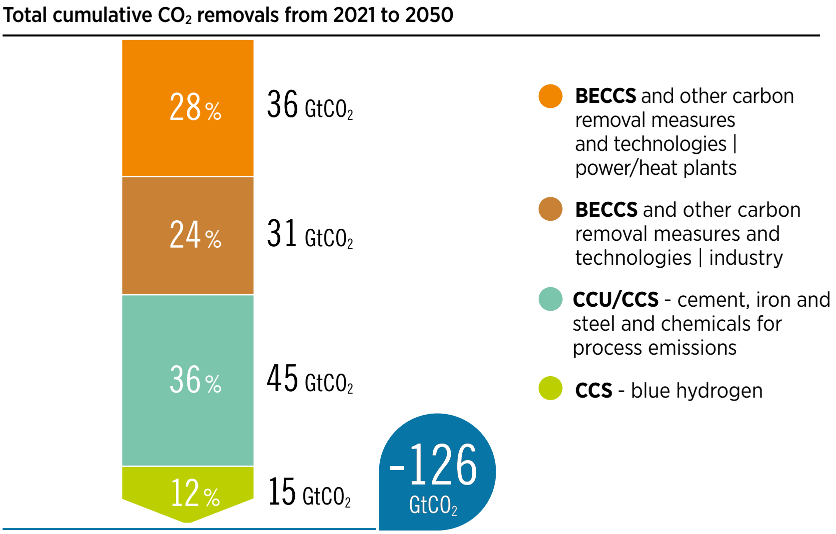
Some examples of BECCS include: power and heat generation with biomass (*e.g.* wood pellets or sugarcane bagasse) where CO_2 is captured and stored; capture of CO_2 in cement kilns and iron blast furnaces where charcoal might be used as fuel; CO_2 capture in chemical plants where the feedstock is biomass (*e.g.* in bioethanol production and other bioplastics); and capture of CO_2 from biogas upgrading where the CO_2 fraction of biogas is separated for the production of biomethane. In the 1.5°C Scenario, BECCS will play a role mainly in power, cogeneration plants and industry (*e.g.* cement) which in total would lead to nearly 4 $GtCO_2$ per annum captured and stored by BECCS in 2050, compared to less than 2 million tonnes CO_2 captured in 2020.

In the 1.5°C Scenario, the role of CCS is limited; its main application is in capturing process emissions in cement, iron and steel, and chemical production; its limited deployment for industry/waste incinerators among others is less common. The application of carbon capture and utilisation (CCU)** for fossil-fuel or process emissions will have a limited role in the short term. CCU/CCS in industry and CCS for blue hydrogen would increase to around 3 $GtCO_2$ captured in 2050 from 0.04 Gt per annum today. This includes the carbon balance in the chemical and petrochemical industry such as carbon stocks in chemical products, recycling and carbon capture in waste incineration.

** A variant of CCS is the so-called carbon capture and utilisation (CCU), which means that after being captured, the CO_2 is not stored in a reservoir but instead is utilised, for instance, as a source of carbon in a chemical process. This would be akin to recycling carbon. It must be emphasised that CCU may not lead to permanent removal of CO_2 from the atmosphere. In certain cases, the carbon captured and utilised will return to the atmosphere in the form of CO_2 during the use-phase of the product that contained that carbon. This must be addressed on a case-by-case basis.

FIGURE 12 The role of bioenergy with carbon capture and storage (BECCS)

CO_2 removals, $GtCO_2$ cumulative 2021–2050, in the 1.5°C Scenario



Note: CCU = carbon capture and utilisation; $GtCO_2$ = gigatonnes of carbon dioxide.

Bioenergy combined with CCS (BECCS) would play a key role in power plants, co-generation plants and in industry specifically for the cement and chemical sectors, to bring negative emissions in line with a very constrained carbon budget. BECCS would contribute over 52% of the carbon captured over the period to 2050. Besides BECCS, the role of CCS remains limited mainly to CO_2 process emissions in cement and iron and steel (where limited alternative technologies exist beyond the accelerated adoption of renewables, energy efficiency, relocation of steel production with direct reduced iron and material improvements as part of the circular economy considered in the 1.5-S) and blue hydrogen production.

PHASING OUT FOSSIL FUELS

Fossil fuel use could decline by more than 75% by 2050, based on the rapid transition measures starting now.

By 2050 in the 1.5°C Scenario, fossil fuel production declines by more than 75% with total fossil fuel consumption continuously declining from 2021 onwards. Fossil fuels still have roles to play, mainly in power and to an extent in industry, providing 19% of the primary energy supply in 2050. Oil and coal decline fastest while natural gas peaks around 2025 and decline thereafter. Natural gas is the largest remaining source of fossil fuel in 2050 (70% of total fossil fuel supply), at around 52% of today's level. Natural gas production amounts to 2.2 trillion cubic metres (or 79 EJ) in 2050, down from around 4.2 trillion cubic meters (153 EJ) today. Around 70% of the natural gas is consumed in power/heat plants and blue hydrogen production. The other relevant use is in industry. The global production of oil declines to just above 11 million barrels per day in 2050, roughly 85% lower than today. This oil is largely used in industry for petrochemicals (non-energy uses, close to 40%), and in aviation and shipping. Coal production declines more drastically, from around 5 750 million tonnes in 2018 (160 EJ) to almost 240 million tonnes per year (7 EJ) in 2050. Specifically, in the power sector, coal generation declines significantly to 55% by 2030, 75% by 2040 compared to current levels and by 2050 has been phased out. While coal is largely used in industry, it is mostly for steel (by 2050, 5% of total steel production coupled with CCS) and to a certain extent in chemicals production.

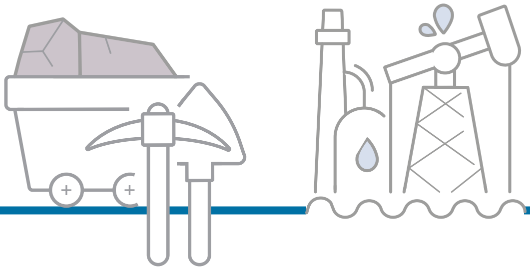
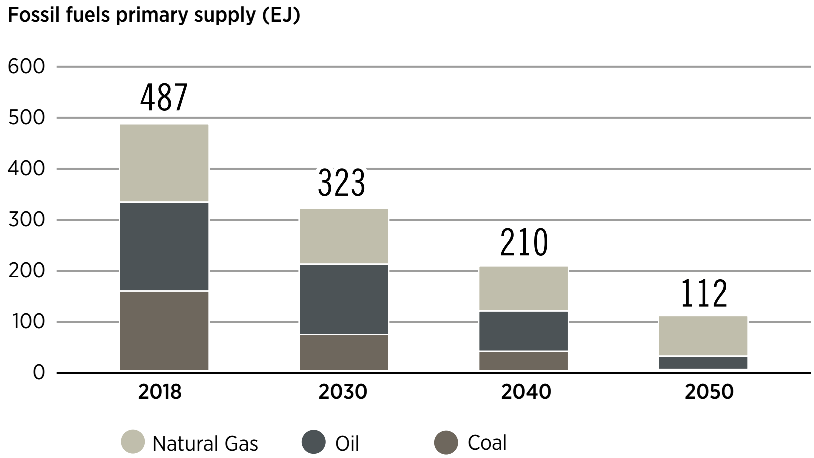


FIGURE 13 The declining importance of fossil fuels

Fossil fuel primary supply, 2018 to 2050 (EJ) in the 1.5°C Scenario

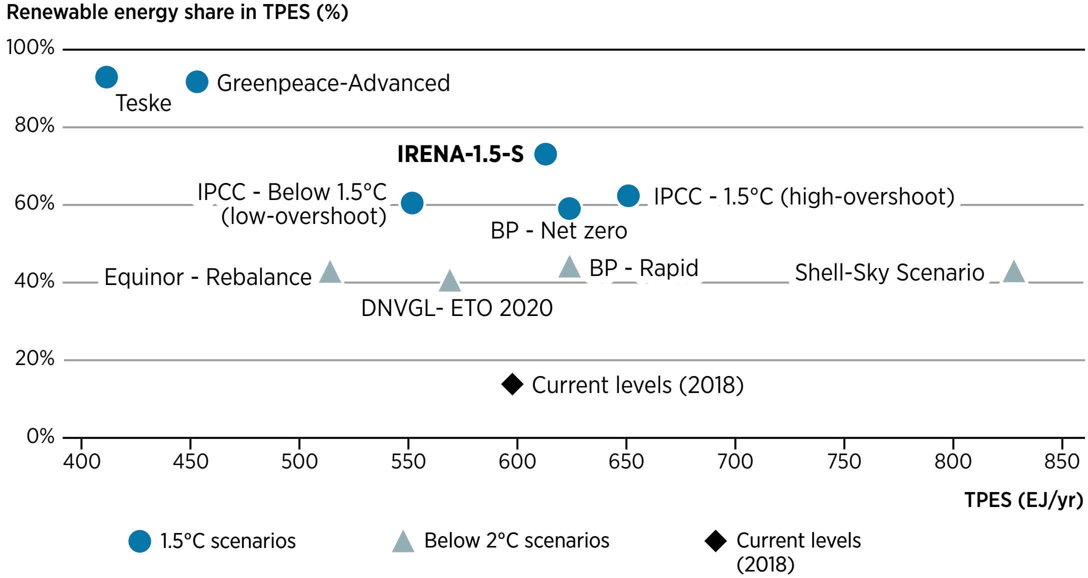


Note: EJ = exajoule.

With accelerated uptake of renewables, fossil fuel use would drop significantly from almost 487 EJ in 2018 to 112 EJ in 2050. This implies that only a quarter of today's fossil fuel demand remains by 2050. Oil demand would decline significantly by around 85% by 2050 compared to the 2018 level. Coal as a fuel for power generation would be phased out by 2050 and the remaining coal demand would be largely only in industry, mostly for steel production (coupled with CCS) and to a certain extent in chemicals production. Natural gas would be the largest source of fossil fuel in 2050 with a share in total primary energy supply dropping to 13% from 26% in 2018. In 2050, natural gas would primarily be used in power plants, industrial processes and for blue hydrogen production (coupled with CCS).

FIGURE 14 Emerging consensus on the role of renewables and electrification

Shares of renewables in total primary energy in 2018 and 2050 in various energy scenarios



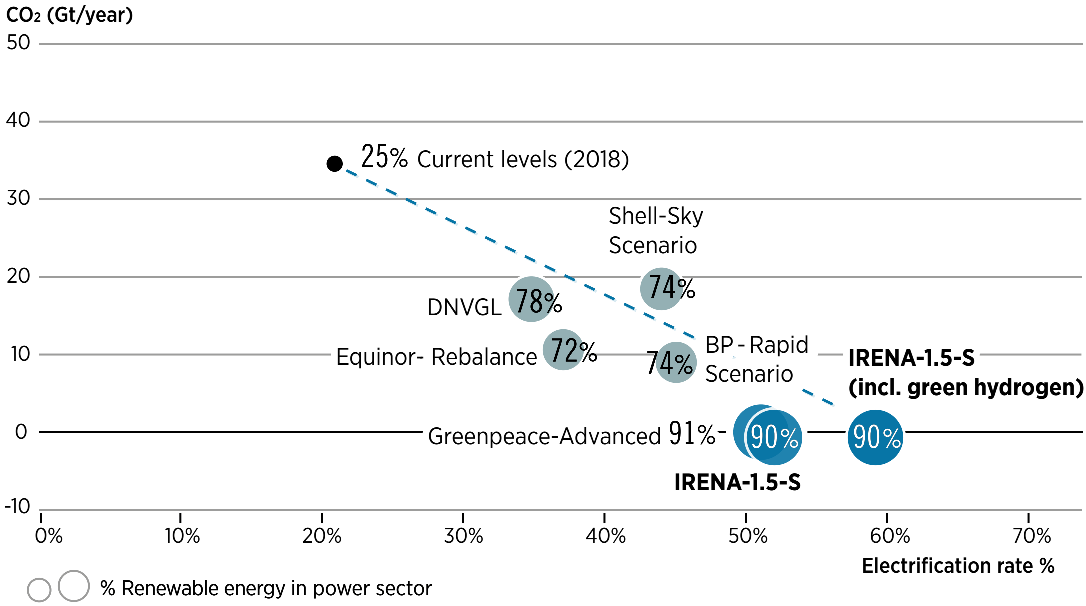
Sources: Shell's 2018 "Sky" scenario (Shell, 2018); British Petroleum's "Rapid Scenario"(British Petroleum, 2020); the IPCC - Below 1.5°C (low-overshoot) and IPCC - Below 1.5°C (high-overshoot) scenario from the Intergovernmental Panel on Climate Change (IPCC, 2018); Greenpeace's 2015 "Advanced" scenario (Greenpeace, 2015); Teske's "Achieving the Paris Climate Agreement Goals" (Teske, 2019); Equinor's "Rebalance scenario" (Equinor, 2020) and DNVGL's Energy Transition Outlook 2020 (DNVGL, 2020).

Note: The figure includes current level (2018) and 2050 projections from various energy scenarios aligned with Paris climate targets from different institutions. IPCC's (2018) special report on global warming of 1.5°C assessed several energy scenarios from different institutions and aggregated them into two 2°C and three 1.5°C pathway classes. Of these, the assessed "below 1.5°C" and "1.5°C-low-overshoot" pathways have a mean total primary energy supply equal to 553.23 EJ with a range between 289.02 EJ and 725.40 EJ (derived from the IPCC's SR15 2018 report, page 132, Table 2.6) in 2050. The mean share of renewables in total primary supply in those pathways is 60.24% with a range between 38.03% and 87.89%. For the "1.5°C-high-overshoot" pathway, the mean primary supply is 651.46 EJ (1012.50 EJ, 415.31 EJ) and the share of renewables in primary supply is 62.12% (86.26%, 28.47%). EJ/yr = exajoules per year; $GtCO_2$ = gigatonnes of carbon dioxide; IPCC = Intergovernmental Panel on Climate Change; PES = Planned Energy Scenario. This figure does not include scenarios that contain 2040 projections, for instance, IEA's Sustainable Development Scenario (SDS) and Total's "Rupture".

The energy scenarios examined show different visions of the future. There is a significant difference between achieving the 1.5°C target versus net zero emissions. All energy scenarios propose higher renewable energy shares in primary supply compared to 2018, with nearly half of them showing lower primary supply, which indicates greater energy efficiency. All result in lower emissions.

FIGURE 15 **Global energy-related CO_2 emissions in 2050**

CO_2 emissions versus electrification rates in various energy scenarios



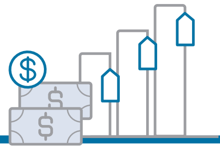
Sources: Shell's 2018 "Sky" scenario (Shell, 2018); British Petroleum's "Rapid Scenario"(British Petroleum, 2020); the IPCC - Below 1.5°C (low-overshoot) and IPCC - Below 1.5°C (high-overshoot) scenario from the Intergovernmental Panel on Climate Change (IPCC, 2018); Greenpeace's 2015 "Advanced" scenario (Greenpeace, 2015); Teske's "Achieving the Paris Climate Agreement Goals" (Teske, 2019); Equinor's "Rebalance scenario" (Equinor, 2020) and DNVGL's Energy Transition Outlook 2020 (DNVGL, 2020).

Note: The size of the bubbles in the figure and the number indicated beside the scenario description reflect the share of renewables in the power sector in various scenarios. CO_2 = carbon dioxide; Gt = gigatonnes.

Despite the differences among the energy scenarios, there is a clear consensus on the important role that electrification powered by renewable energy sources has in the decarbonisation of the energy system. With a share of 51% of direct electrification and 58% if green hydrogen and its derivates are included, coupled with 90% of renewables in the power sector in 2050, IRENA's 1.5°C Scenario shows a higher electrification rate than the other scenarios.

ENERGY TRANSITION INVESTMENT OPPORTUNITIES

Energy investments need to shift to low-carbon energy transition solutions and increase 30% overall.



Government plans in place today call for investing almost USD 98 trillion in energy systems over the coming three decades. The economic stimulus packages announced so far would direct USD 4.6 trillion into sectors that have a large and lasting impact on carbon emissions, namely in agriculture, industry, waste, energy and transport, of which less than USD 1.8 trillion is green.[23]

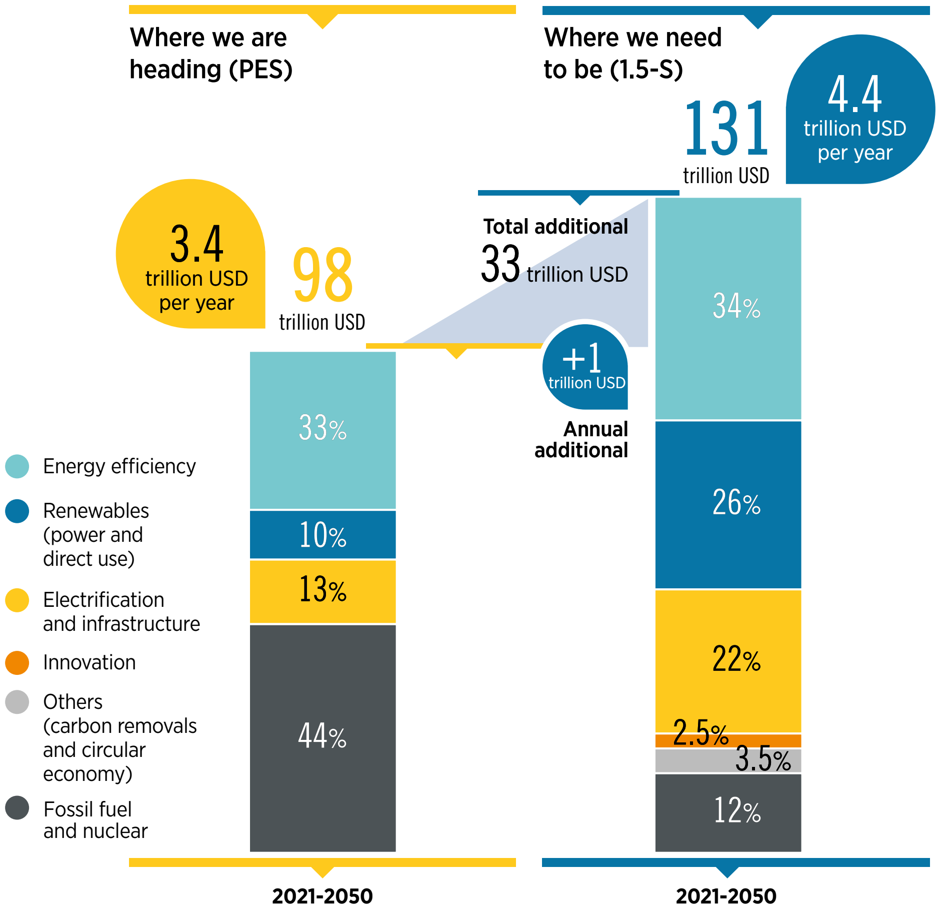
To ensure a sustainable, climate-safe and more resilient future, significant investments need to flow into an energy system that prioritises renewables, electrification, efficiency and associated energy infrastructure. At the same time, those investments must not lead to lock-in effects that are not compatible with the 1.5°C Scenario. IRENA's 1.5°C Scenario could be achieved with an additional USD 33 trillion over the planned investments, for a total investment of USD 131 trillion over the period to 2050 as shown in Figure 16. Over 80% (USD 116 trillion for the period to 2050 or around USD 4 trillion per year on average as shown in Table 1) needs to be invested in energy transition technologies (excluding fossil fuels and nuclear) such as renewables, energy efficiency, end-use electrification, power grids, flexibility innovation (hydrogen) and carbon removal measures.

The 1.5°C Scenario shows that cumulative investments of over USD 24 trillion should be redirected from fossil fuels to energy transition technologies over the period to 2050. In annual terms, an over two-fold rise in energy sector investments to USD 4.4 trillion per year until 2050 would be needed compared to USD 1.8 trillion invested in 2019 4.4 trillion or nearly 5% of global estimated gross domestic product today.[20] Compared to the PES, USD 1.1 trillion additional energy sector investments would be needed in the next three decades.

Over the more immediate term, up to 2030, cumulative investments in the energy system, including infrastructure and efficiency, would reach USD 57 trillion. In addition to money for research and development, equipment and infrastructure, investments in people are needed, including for training and reskilling, labour market programmes, economic development and social protection measures.

FIGURE 16 **New investment priorities: renewables, efficiency and electrification along with infrastructure**

Cumulative investments 2021–2050 (USD trillion) in the 1.5°C Scenario and the PES



A climate-safe future calls for the scale-up (additional USD 1.1 trillion per year in the 1.5°C pathway compared to the PES), and redirection of investments from fossil fuels towards energy transition technologies – renewables, energy efficiency and electrification of heat and transport applications. High upfront investment is crucial mainly to enable accelerated deployment of key renewable energy technologies such as wind and solar PV in the power sector, massive scale-up of electrification of transport and heat applications along with expansion of infrastructure followed by large-scale green hydrogen projects.

TABLE 1 Energy transition investment needs to be scaled up significantly in the coming decades

Energy transition annual average investments, USD billion per year, 1.5°C Scenario

Power

		Annual average investments USD billion/yr Historical 2017-19	1.5S 2021-50
Power generation capacity	Hydro - all (excl. pumped)	22	85
	Biomass (total)	13	69
	Solar PV (utility and rooftop)	115	237
	CSP	3	84
	Wind onshore	80	212
	Wind offshore	18	177
	Geothermal	3	24
	Marine	0	59
Grids and flexibility	Electricity network	271	600
	Flexibility measures (*e.g.* storage)	4	133

Continues next page

Note: This table does not include fossil fuel and nuclear investments.

Power generation capacity: Deployment of renewable technologies for power generation. Grids: Transmission and distribution networks, smart meters, pumped hydropower, decentralised and utility-scale stationary battery storage (coupled mainly with decentralised PV systems) and hydrogen for seasonal storage.

Renewables, direct uses and district heat: Renewables in direct end-use and district heat applications (e.g. solar thermal, modern bio-energy).

Energy efficiency in industry: Improving processes efficiency, demand-side management solutions, highly efficient energy and motor systems and improved waste processes.

Energy efficiency in transport: All passenger and freight transport modes, notably road, rail, aviation and shipping. Key efficiency measures include light-weight materials, low-friction designs, aerodynamic improvements, among others.

Energy efficiency in buildings: Improving building thermal envelopes (insulation, windows, doors, etc.), deploying efficient lighting and appliances, equipping smart homes with advanced control equipment, replacing less efficient buildings with energy-efficient buildings.

Hydrogen – electrolysers and infrastructure: Electrolyser capacity (alkaline and polymer electrolyte membrane) for the production of green hydrogen and infrastructure for the transport of hydrogen.

Bio- and hydrogen-based ammonia and methanol: Production of ammonia and methanol from biomass and hydrogen feedstocks.

Carbon removals: CCS deployment mainly for process emissions in industry and blue hydrogen production. BECCS deployment in cement and power and cogeneration plants.

Circular economy: Material and chemicals recycling and bio-based alternative products (e.g. bioplastics).

BECCS = bio-energy with CCS; CCS = carbon capture and storage; CSP = concentrated solar power.

TABLE 1 Energy transition investment needs to be scaled up significantly in the coming decades

Energy transition annual average investments, USD billion per year, 1.5°C Scenario

End uses and district heat

		Historical 2017-19 (USD billion/yr)	1.5S 2021-50 (USD billion/yr)
Renewables end uses and district heat	Biofuels - supply	2	88
	Renewables direct uses and district heat	31	84
Energy efficiency	Buildings	139	963
	Transport	45	385
	Industry	65	157
Electrification	Charging infrastructure for electric vehicles	2	131
	Heat pumps	12	102
Innovation	Hydrogen - electrolysers and infrastructure	0	78
	Bio-based ammonia	0	22
	Bio-based methanol	0	12
Carbon removals	Carbon removals (CCS, BECCS)	0	78
Circular economy	Recycling and biobased products	0	70

Total average investments
(excluding fossil fuel and nuclear)
2017-2019

824 USD billion/year

Total average investments
(excluding fossil fuel and nuclear)
2021-2050

3 849 USD billion/year

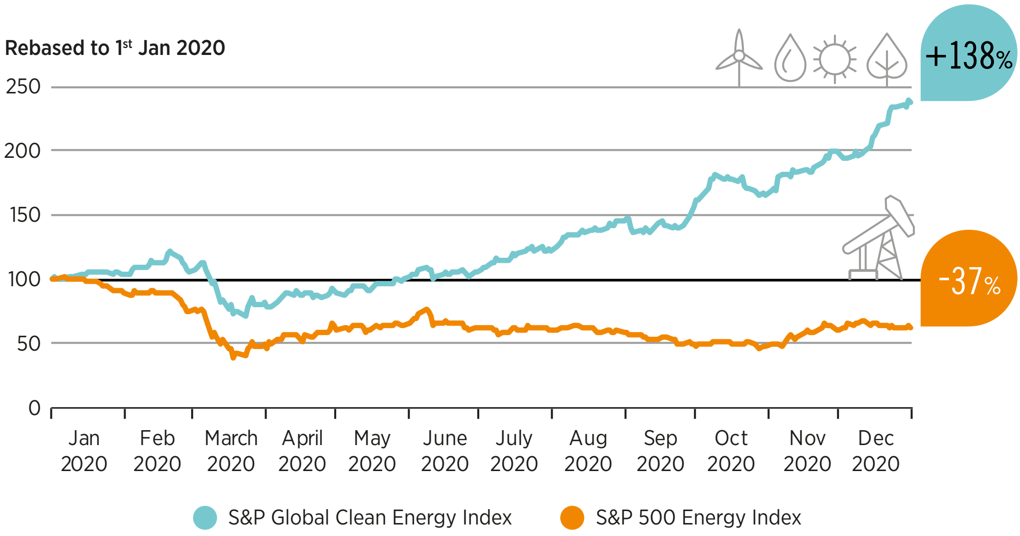
Financial markets and investors are already shifting their attention towards the opportunity of new energy technologies.

Capital is already moving to take advantage of the most attractive investment opportunities at this time of transition. Financial markets are anticipating peak demand for fossil fuels and rapid growth for new energy technologies, and allocating capital accordingly. They have been de-rating one fossil fuel sector after another as peak demand for fossil fuel technologies has spread from European electricity to coal to cars to oil services. The de-rating of fossil fuel sectors has been going on for some time, with the share of the fossil-fuel-heavy energy sector in the US S&P 500 index falling, for example, from 13% a decade ago to below 3% today. In 2020, investors got enthusiastic about the renewable opportunity. Money flooded into renewable energy stocks; the S&P clean energy index was up by 138%, while the fossil-fuel-heavy S&P energy index was down by 37%.*

Financial markets speed up change. They bring the future forward because they remove capital from sectors in decline and allocate it to growth sectors. The fossil fuel sector therefore struggles to raise new capital and has to reduce its expansion plans and change its strategy. In contrast, companies driving the energy transition find it relatively easy to raise capital and to expand fast, and this speeds up the process of change. For example, in 2015 there were just three mega factories dedicated to producing electric vehicle batteries; today there are over 150 active and planned battery mega factories.

* In the first months of 2021, there was a partial reversal of this trend. However, from January 2020 to March 9 2021, the S&P global clean energy index was nevertheless up by 104% and the S&P 500 energy index was down 15%.

FIGURE 17 **New energy vs. old energy: S&P Global Clean Energy and Energy Indices from January 2020**



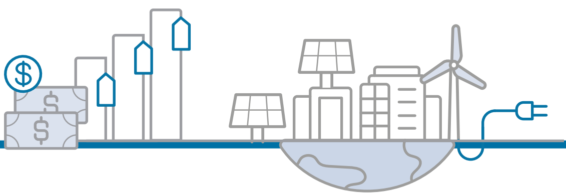
Source: Bloomberg.

Investors and financial markets are anticipating the energy transition and already allocating capital away from fossil fuels and towards energy transition technologies, such as renewables. For example, in 2020, the S&P Clean Energy Index of clean energy stocks was up by 138%, as compared to the fossil fuel-heavy S&P Energy Index which was down by 37%.

The time for action is now, while there's a chance to capitalise on the momentum of investment and spending in the wake of the pandemic.

Countries are fighting the damages of the COVID-19 pandemic with huge sums spent on bailouts and recovery measures. The pathway towards the goals of the 1.5°C Scenario starts now, and public investment must be channelled away from fossil fuels and towards the energy transition, including enabling infrastructure for the efficient use of renewable power (*e.g.* smart grids, cross-country interconnectors), heat (*e.g.* district heating and cooling networks) and transport (*e.g.* charging stations for electric vehicles). At the same time, energy industry bailouts and financial support to carbon-intensive companies should be made conditional on measurable climate action. With comprehensive, supportive and clear policy frameworks, public investment should also be leveraged to mobilise energy transition-related investment. Important government actions include the provision of risk-mitigation instruments (*e.g.* guarantees, currency hedging instruments and liquidity reserve facilities) to attract and de-risk private capital; creation of pipelines of bankable renewable energy projects; establishment of sustainability requirements for investors (*e.g.* climate-risk analysis and disclosure); provision of reviewed investment restrictions and sustainability mandates for institutional investors; and adoption of standards for green bonds in line with global climate objectives.

Moreover, carbon pricing should be implemented, where possible, to avoid distorted economic uptake as the pandemic recedes. Of course, careful consideration of broader social and equity issues is necessary, particularly for low-income populations, for whom energy constitutes a larger share of household expenditures and whose budgets do not leave many options.



3 BROAD, HOLISTIC JUST **TRANSITION POLICIES**

The energy transitions at all levels depend on setting ambitious targets as part of a broad and comprehensive policy framework.

To further the energy transition and attract the investments needed in the long and short term, ambitious climate and clean energy targets are essential at both national and sub-national levels. In addition to the laws passed or proposed around net zero emissions in many jurisdictions, ambitions expressed in the NDCs must be raised beyond the power sector, covering all end uses.

Targets are only effective within a holistic policy framework, where deployment policies combining financial and fiscal incentives with market pull (*e.g.* regulatory and pricing policies such as auctions) and technology push mechanisms (*e.g.* mandates) go hand in hand with enabling policies such as measures to ensure the reliability of technology and system integration policies. The prevalent organisational structure of electricity systems, designed mainly for conventional, centralised power generation, requires fundamental changes to accommodate the increasing share of VRE such as solar and wind and the rise of decentralised power generation.

Policies supporting and enabling deployment and integration of renewable energy must go hand in hand with a broader set of policies that ensures industrial and other economic capabilities are aligned with recovery, development and climate objectives; and fosters a just transition through labour, skills, education and social protection measures.

Off-grid solutions will play a major role in providing universal access to clean and reliable energy. In this context, a specific ecosystem is needed to support livelihoods, which includes efficient technologies that cater to specific needs; awareness regarding available solutions and skills to distribute, install and maintain them; integrated resource planning as part of national-level policies and targets; and access to finance, de-risking tools and conducive ownership models.

There is no single policy to achieve the trajectory of the 1.5°C Scenario in a socially sustainable manner. A set of mutually reinforcing policies (see Figure 18), tailored to specific country contexts and objectives, are at the core of the transition.

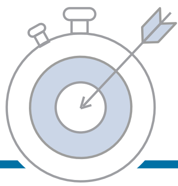
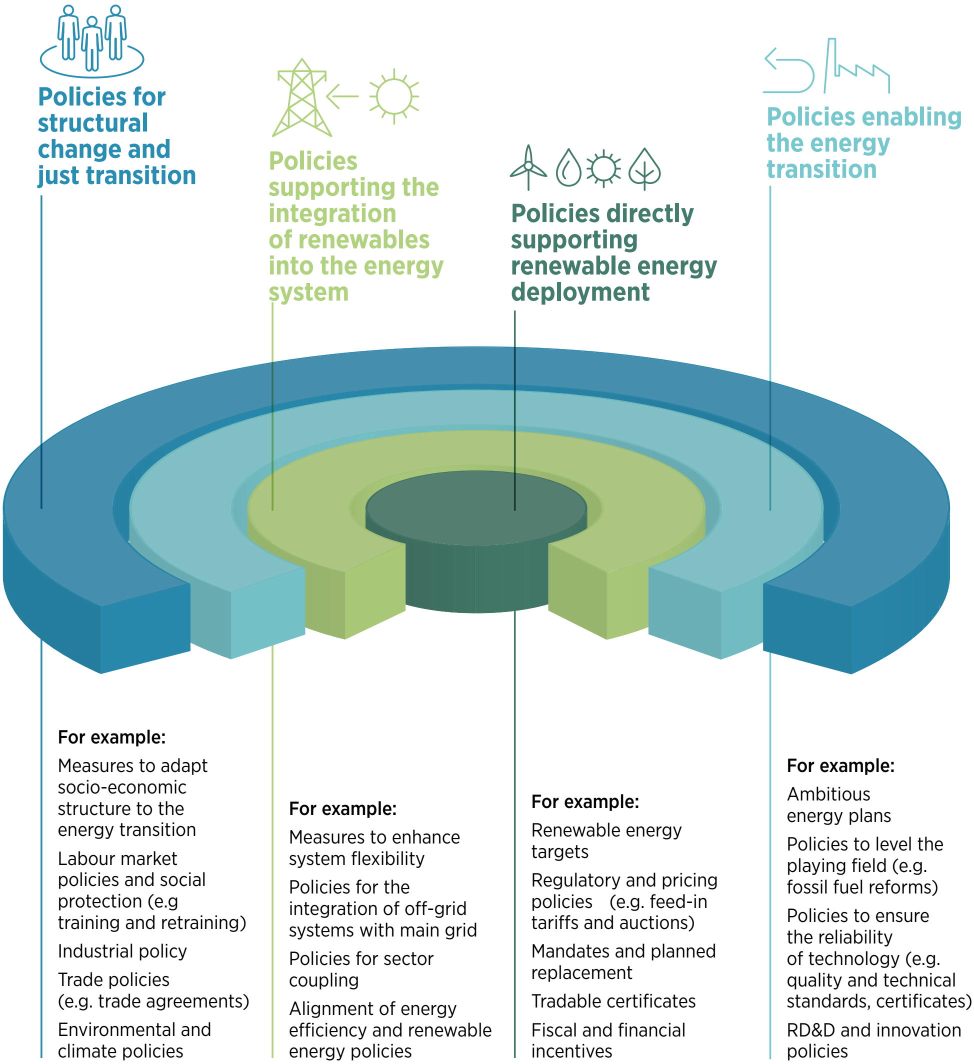


FIGURE 18 **Enabling policy framework for a just energy transition**



A broad set of policy measures is required to align the short-term recovery with longer-term transition, climate and socio-economic development objectives.

IRENA's socio-economic footprint analysis provides an integrated systemic approach to evaluate the outcomes of energy transition pathways.

The 1.5°C Scenario outlined in this preview points to a more sustainable energy system and lays the foundation for new patterns of socio-economic development. The energy transition cannot be considered in isolation, separate from the socio-economic system in which it is deployed. Understanding the socio-economic footprint of the energy transition is essential to optimising the outcome. If well understood and planned, structural socio-economic changes will improve the outcome of the transition and support its pace. A holistic assessment can inform energy system planning, economic policy making and other policies necessary to ensure a just and inclusive energy transition at global, regional and national levels.

The economic, social and environmental outcomes of multi-systemic interactions taking place during the energy transition are evaluated using socio-economic indicators, including economic activity (gross domestic product), jobs and a comprehensive welfare indicator that includes economic, social (including health), environmental and distributional dimensions. These are fundamental to the rapid transition needed to stabilise global warming at 1.5°C. Triggering the required collaborative framework for all of society requires inclusive policies that can properly address concerns about fair and just outcomes, both within and between countries.

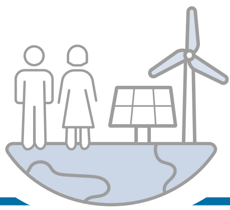
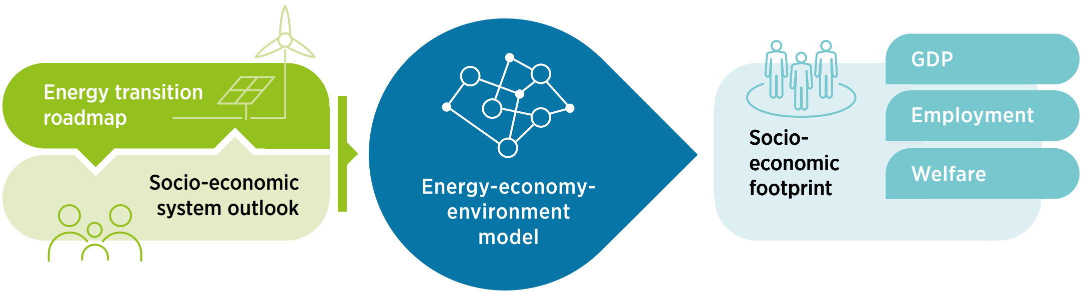


FIGURE 19 **Measuring the socio-economic footprint of transition roadmaps**



Note: GDP = gross domestic product.

Socio-economic systems will play a fundamental role in deploying fast transitions needed to stabilise global warming at 1.5°C. Social and economic policy, based on collaborative frameworks, can address the fairness and justice dimensions, both within and between countries.

4 JOB CREATION AND WIDER BENEFITS

The energy transition has the potential to deliver comprehensive socio-economic benefits, in terms of jobs and overall welfare, with the most direct impact on the energy sector.

The transition opens jobs in renewable energy, energy efficiency, electrification and green fuels. Globally, employment in the 1.5°C Scenario follows a higher growth path than under currently planned pathways. Overall welfare gains are even higher because they comprise improved health, less pollution and better incomes. To fully reap these potential benefits, distributional aspects need to be addressed and included in policy action from the very onset.

Both positive and negative employment effects are brought about by the energy transition in the energy sector. On the positive side, the energy transition brings about new jobs in renewables, efficiency and energy system flexibility. Investing in energy transition technologies creates close to three times more jobs than fossil fuels do for each million dollars of spending. But the energy transition also entails the phase-out of fossil fuels, which currently contribute a significant share of energy sector employment. At the global level, the employment balance is positive, with the 1.5°C Scenario providing an increase of total energy sector jobs over currently planned activities.

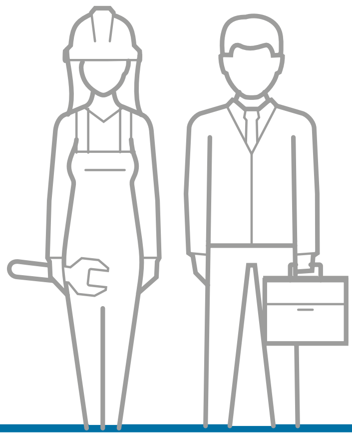
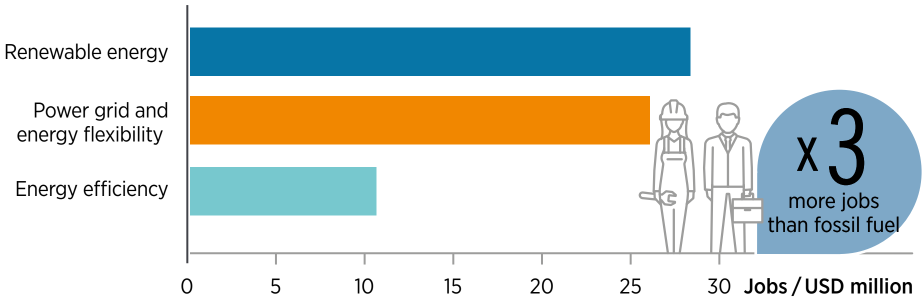


FIGURE 20 **Employment intensities of transition-related technologies**



Investing in energy transition technologies creates up to three times more jobs than do fossil fuels, for each million dollars of spending.

Renewable energy drives the positive impact of the transition on energy sector jobs.

The energy transition leads to additional employment in a wide spectrum of activities along the renewable energy, energy efficiency and grid enhancement supply chains. These include jobs in academia and research, testing, manufacturing, installing, and operating and maintaining renewable energy technologies. Other sectoral and economy-wide transition dynamics are sure to affect the evolution of employment in the broader energy sector.

The job outcomes for individual countries or regions depend not only on their readiness for renewables, but also on their economic structures, the skills and capacities they can marshal, and the degree to which these resources can be aligned with the challenges and opportunities brought about by the transition. To ensure that an expanding renewable energy workforce possesses the right knowledge and skillsets requires appropriate education and training programmes, re-training and social protection, co-ordination between industry and educational entities, and active labour market measures, among other measures.

The energy transition affects all economic sectors.

The energy transition has effects throughout the whole economy – most directly along the value chains of renewable energy technologies, but also in other areas such as energy-efficient appliances and machines, and all other products and services necessary to make it work. Transition investments lead to indirect economic effects from new demand for goods and services along the value chain, as well as induced effects enabled by growing disposable income due to more jobs and energy savings. Overall, this contributes to additional growth. But it also induces shifts in economic structures, prompting adjustments in the workforce with regard to qualifications and skills. Policies need to be introduced with foresight and at an early stage to be ready for the structural change and "stockpile" the right skills.

Distributional effects are manifold and need to be addressed adequately for a just transition.

Whether in terms of long-term effects of climate change or immediate consequences of the pandemic, negative impacts are distributed unevenly. Vulnerable groups, regions and countries with insufficient access to health, infrastructure and energy are less equipped to deal with the pandemic. The health crisis joins global warming–related challenges such as wildfires, heat waves, flooding, droughts, fluctuations in agricultural yields, limited availability of water resources and rising climate migration.

The energy transition can improve resilience by improving energy access and more distributed, democratic ownership of energy resources. Transition policies can trigger both positive and negative distributional dynamics. A holistic and consistent policy framework can tilt the balance towards the positive side, embedding justice and fairness into the transition process. Policy measures that not just promise but ensure that no one is left behind will increase public acceptance when waves of deep structural change, disaster impacts and repeated economic disruption have unsettled the public discourse and traditional policy processes.

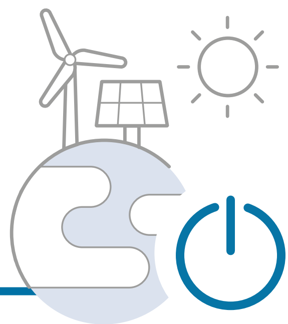
5 CO-OPERATION BEYOND BORDERS

Energy transitions require far-reaching international co-operation to reduce regional disparities and ensure a successful global outcome.

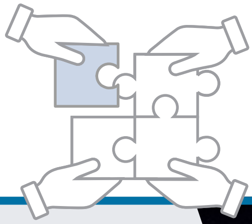
The geopolitics of energy will change profoundly, with implications for international rule making and co-operation among suppliers and buyers of minerals and resources essential for the energy transition. Part of the challenge is establishing a commercially viable market for green hydrogen and therefore developing rules governing global markets. Prices need to reflect the benefits of energy transition technologies and reflect the damages from fossil fuels.

Further, there is a need to establish transparent, secure, sustainable and fair supply chains for critical materials such as copper, lithium, cobalt and platinum, and rare earth metals. At the same time standards and certification systems will be needed for green hydrogen and green commodities. On a human skills level, technical development and training programmes are crucial. International trade will remain a cornerstone of future sustainable development and with appropriate regulations, technology innovation can benefit all nations.

These transformative changes cannot be left to markets alone and indeed surpass their ability. Therefore, international co-operation in accelerating the energy transition should be strengthened further. Co-ordinated government action is needed at several levels to make suitable rules governing these new markets; harness the relevant technical, economic, social and environmental expertise; and ensure sufficient cohesion and unity in pursuit of shared goals.



The energy transition is a multi-systemic process that reaches far beyond the energy sector.



The interactions and feedbacks among the energy, economic, social and eco- systems determine the outcome of transitions and their viability. Hence, transition planning and policy making should be, from the onset, based on insights into these systemic interactions. Limiting global warming to 1.5°C, given the starting situation in 2021, requires an extremely fast rate of change. During accelerated transformations, even greater attention needs to be given to systemic interactions to avoid undesired socio-economic outcomes. Hence, a holistic transition policy framework is imperative.

Climate damages will have a significant impact on economic activity, which increases as emissions rise, inflection points in global ecosystems are reached and previously unknown feedback loops are triggered. In economic terms, there is no such thing as a scenario without climate change. The low cumulative emissions associated with the 1.5°C Scenario minimise further effects of climate damages, increasing the economic benefits over the currently planned energy pathways.

1.5°C PATHWAY

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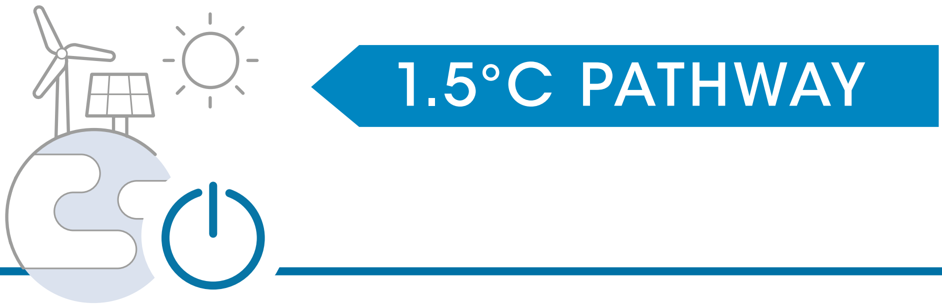

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