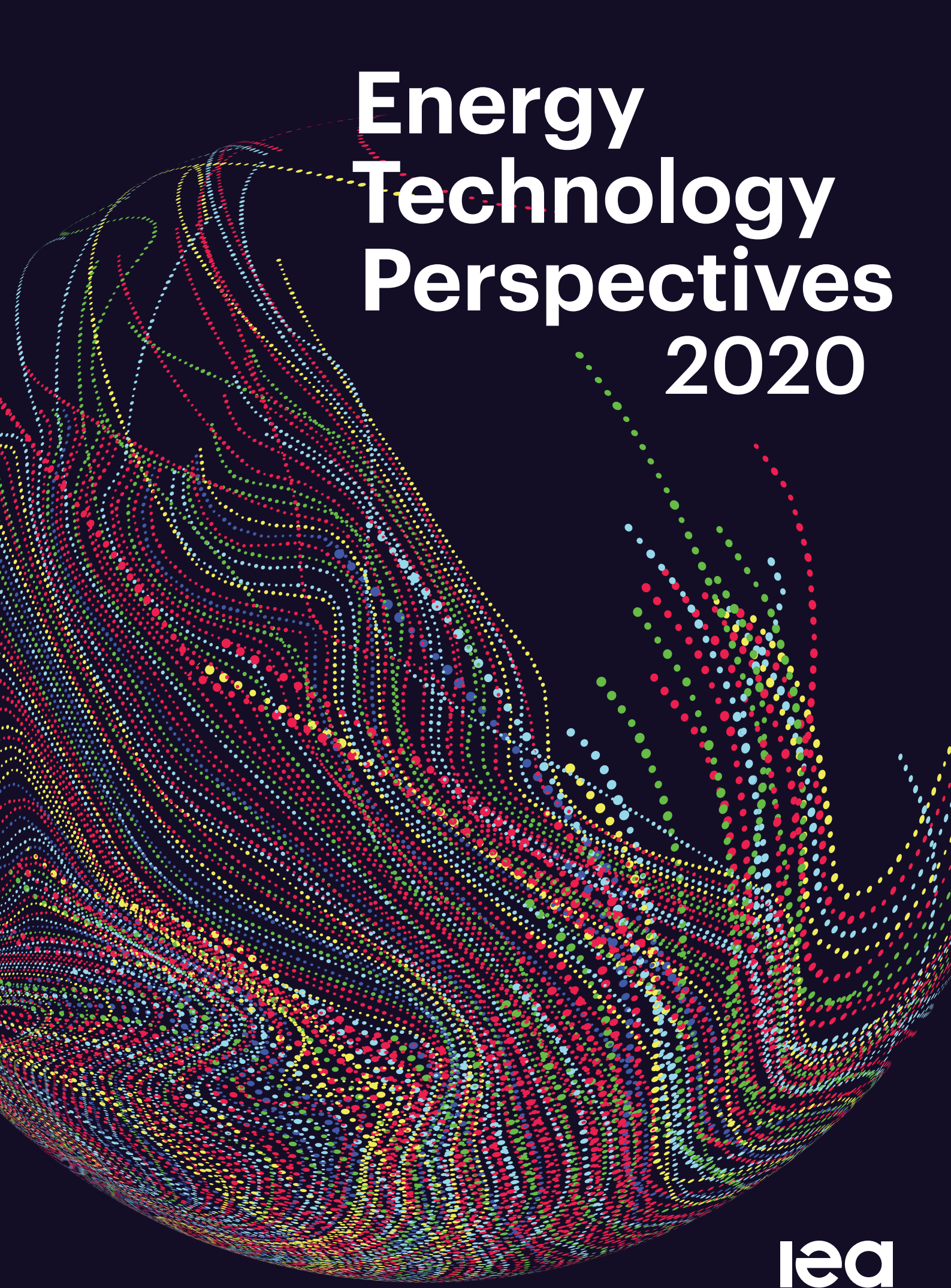
Energy Technology Perspectives 2020



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Energy Technology Perspectives 2020

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Foreword

Technology will largely determine our energy future. The International Energy Agency (IEA) has long been cognizant of this, which is why for more than a decade we have produced the *Energy Technologies Perspectives* (*ETP*) series to help inform policy makers as they plan for the sustainable and resilient energy systems that people and businesses will need in the years to come.

When I became Executive Director of the IEA in late 2015, it was clear to me that the ETP was in need of a revamp to increase its relevance for decision makers in government and industry. My objective was to prepare "a global guidebook on clean energy technologies" for policy makers and others seeking to navigate the fast-evolving technological developments across a wide range of energy-related sectors. With the publication of this report, *Energy Technologies Perspectives* 2020, I believe we have come close to reaching that objective.

This report is an essential contribution to the global conversation on energy. As the report's rigorous analysis makes clear, achieving international climate goals hinges on dramatically scaling up clean energy technologies to reduce greenhouse gas emissions. And having those technologies ready in time hinges on a rapid acceleration in innovation. In the *ETP Special Report on Clean Energy Innovation* that was published in July, we examined the innovation element of that challenge. This report, *ETP-2020*, gives the full picture, analysing the major energy technology challenge the world faces and identifying the needs and opportunities that result from it.

Today, I am increasingly optimistic about the world's clean energy future, despite the grave challenges we face. *ETP-2020* shows that we know what needs to be done to develop and deploy the technologies that can put emissions on a sustainable path. The spectacular success of solar PV in becoming the cheapest source of power in many economies and the impressive rise of offshore wind demonstrate the ability of clean energy technologies to break through if governments put in place the right policies to support their expansion.

At the same time, more and more governments around the world are backing clean energy technologies as part of their economic recovery plans in response to the Covid-19 crisis – as was made clear by many of the 40 Ministers who attended the IEA Clean Energy Transitions Summit on 9 July 2020. The private sector is also upping its game, with some oil and gas majors betting their futures on becoming lower-carbon energy companies and top information technology companies putting increasing resources into renewables and energy storage. Moreover, investments in

clean energy projects can benefit from the extended period of extremely low interest rates in some regions that appears likely following the massive easing of monetary policy by central banks in response to the Covid-19 crisis.

As the ETP analysis underscores, energy innovation will be crucial. Despite the disruption and uncertainty caused by the pandemic, I see reason for optimism there, too. Investment in clean energy start-ups by venture capital funds and companies rose to a new record in 2019. And governments and businesses are finally putting serious resources into the clean energy potential of hydrogen, which this report makes clear will be critical for reaching net-zero emissions.

However, my optimism should not be mistaken for naivety. Even if these encouraging trends continue, there are significant challenges to overcome. For instance, more work needs to go into mapping out pathways for fair and inclusive clean energy transitions for all parts of the world. Moreover, huge portions of the global energy sector are yet to make reducing their emissions a top priority.

The major challenge studied in depth in this report is how to tackle emissions from the vast amount of existing energy-related infrastructure around the world. The enormous fleets of inefficient coal plants, steel foundries, chemical facilities and cement factories – many of them recently built – are set to produce enough emissions in the coming decades to put international climate goals out of reach. But, as *ETP-2020* shows, we can develop the technologies to address this through smart policies and investments today.

The transformation of ETP has been three years in the making and has involved a tremendous amount of hard work from the team behind it. I would particularly like to thank Timur Gül for leading the overhaul of the series and his team for the research, modelling and writing that has produced these important reports. I look forward to many more ETP publications full of valuable insights and guidance in the years to come.

Dr. Fatih Birol

Executive Director

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Executive summary

Achieving our energy and climate goals demands a dramatic scaling up of clean energy technologies

To avoid the worst consequences of climate change, the global energy system must rapidly reduce its emissions. Calls to reduce global greenhouse gas emissions are growing louder every year, but emissions remain at unsustainably high levels. International climate goals call for emissions to peak as soon as possible and then decline rapidly to reach net-zero in the second half of this century. The vast majority of global CO_2 emissions come from the energy sector, making clear the need for a cleaner energy system. Global CO_2 emissions are set to fall in 2020 because of the Covid-19 crisis, but without structural changes to the energy system, this decline will be only temporary.

Achieving net-zero emissions requires a radical transformation in the way we supply, transform and use energy. The rapid growth of wind, solar and electric cars has shown the potential of new clean energy technologies to bring down emissions. Net-zero emissions will require these technologies to be deployed on a far greater scale, in tandem with the development and massive rollout of many other clean energy solutions that are currently at an earlier stage of development, such as numerous applications of hydrogen and carbon capture. The IEA's Sustainable Development Scenario – a roadmap for meeting international climate and energy goals – brings the global energy system to net-zero emissions by 2070, incorporating aspects of behavioural change alongside a profound transformation in energy system technology and infrastructure.

This report analyses over 800 technology options to examine what would need to happen for the world to reach net-zero emissions by 2050. The report focuses primarily on the Sustainable Development Scenario, but it also includes a complementary Faster Innovation Case that explores the technology implications of reaching net-zero emissions globally by 2050. The analysis seeks to assess the challenges and opportunities associated with a rapid, clean energy transition. The report covers all areas of the energy system, from fuel transformation and power generation to aviation and steel production.

Transforming the power sector alone would only get the world one-third of the way to net-zero emissions

Many governments have ambitious plans for reducing emissions from the energy sector. Some governments have even put net-zero ambitions into law or proposed legislation, while others are discussing their own net-zero strategies. Many companies have also announced carbon-neutral targets. The success of renewable power technologies gives governments and businesses some cause for optimism. But reaching these targets will require devoting far more attention to the transport, industry and buildings sectors, which today account for more than 55% of CO_2 emissions from the energy system.

Spreading the use of electricity into more parts of the economy is the single largest contributor to reaching net-zero emissions. In the Sustainable Development Scenario, final electricity demand more than doubles. This growth is driven by using electricity to power cars, buses and trucks; to produce recycled metals and provide heat for industry; and to supply the energy needed for heating, cooking and other appliances in buildings.

Reaching net-zero emissions in 2050 would require a much more rapid deployment of low-carbon power generation. In the Faster Innovation Case, electricity generation would be about 2.5 times higher in 2050 than it is today, requiring a rate of growth equivalent to adding the entire US power sector every three years. Annual additions of renewable electricity capacity, meanwhile, would need to average around four times the current record, which was reached in 2019.

Electricity cannot decarbonise entire economies alone

Hydrogen extends electricity's reach. On top of the surging demand for electricity from across different parts of the economy, a large amount of additional generation is needed for low-carbon hydrogen. The global capacity of electrolysers, which produce hydrogen from water and electricity, expands to 3 300 GW in the Sustainable Development Scenario, from 0.2 GW today. In order to produce the low-carbon hydrogen required to reach net-zero emissions, these electrolysers would consume twice the amount of electricity the People's Republic of China generates today. This hydrogen forms a bridge between the power sector and industries where the direct use of electricity would be challenging, such as in the production of steel from iron ore or fuelling large ships.

Carbon capture and bioenergy play multifaceted roles. Capturing CO_2 emissions in order to use them sustainably or store them (known as CCUS)[1] is a crucial technology

[1] Our forthcoming *ETP Special Report on CCUS* provides our most in-depth look yet at this critical technology family and its role in reaching net-zero emissions.

for reaching net-zero emissions. In the Sustainable Development Scenario, CCUS is employed in the production of synthetic low-carbon fuels and to remove CO_2 from the atmosphere. It is also vital for producing some of the low-carbon hydrogen that is needed to reach net-zero emissions, mostly in regions with low-cost natural gas resources and available CO_2 storage. At the same time, the use of modern bioenergy triples from today's levels. It is used to directly replace fossil fuels (e.g. biofuels for transport) or to offset emissions indirectly through its combined use with CCUS.

A secure and sustainable energy system with net-zero emissions results in a new generation of major fuels. The security of today's global energy system is underpinned in large part by mature global markets in three key fuels – coal, oil and natural gas – which together account for about 70% of global final energy demand. Electricity, hydrogen, synthetic fuels and bioenergy end up accounting for a similar share of demand in the Sustainable Development Scenario as fossil fuels do today.

The clean energy technologies we will need tomorrow hinge on innovation today

Quicker progress towards net-zero emissions will depend on faster innovation in electrification, hydrogen, bioenergy and CCUS. Just over one-third of the cumulative emissions reductions in the Sustainable Development Scenario stem from technologies that are not commercially available today. In the Faster Innovation Case, this share rises to half. Thirty-five percent of the additional decarbonisation efforts in the Faster Innovation Case come from increased electrification, with around 25% coming from CCUS, around 20% from bioenergy, and around 5% from hydrogen.

Long-distance transport and heavy industry are home to the hardest emissions to reduce. Energy efficiency, material efficiency and avoided transportation demand (e.g. substituting personal car travel with walking or cycling) all play an important role in reducing emissions in long-distance transport and heavy industries. But nearly 60% of cumulative emissions reductions for these sectors in the Sustainable Development Scenario come from technologies that are only at demonstration and prototype stages today. Hydrogen and CCUS account for around half of cumulative emissions reductions in the steel, cement and chemicals sectors. In the trucking, shipping and aviation sectors, the use of alternative fuels – hydrogen, synthetic fuels and biofuels – ranges between 55% and 80%. Highly competitive global markets, the long lifetime of existing assets, and rapidly increasing demand in certain areas further complicate efforts to reduce emissions in these challenging sectors. Fortunately, the engineering skills and knowledge these sectors possess today are an excellent starting point for commercialising the technologies required for tackling these challenges.

Emissions from existing assets are a pivotal challenge

Power and heavy industry together account for about 60% of emissions today from existing energy infrastructure, climbing to nearly 100% in 2050 if no action is taken. Reaching net-zero will depend on how we manage the emissions challenge presented by these sectors' long-lasting assets, many of which were recently built in Asian economies and could operate for decades to come. The situation underscores the need for hydrogen and CCUS technologies. Ensuring that new clean energy technologies are available in time for key investment decisions will be critical. In heavy industries, for example, **s**trategically timed investments could help avoid around 40% of cumulative emissions from existing infrastructure in these sectors.

Governments will need to play the decisive role

While markets are vital for mobilising capital and catalysing innovation, they will not deliver net-zero emissions on their own. Governments have an outsized role to play in supporting transitions towards net-zero emissions. Long-term visions need to be backed up by detailed clean energy strategies involving measures that are tailored to local infrastructure and technology needs. Effective policy toolkits must address five core areas:

- Tackle emissions from existing assets
- Strengthen markets for technologies at an early stage of adoption
- Develop and upgrade infrastructure that enables technology deployment
- Boost support for research, development and demonstration
- Expand international technology collaboration.

Economic stimulus measures in response to the Covid-19 crisis offer a key opportunity to take urgent action that could boost the economy while supporting clean energy and climate goals, including in the five areas above.

Introduction

Objective

The *Energy Technology Perspectives (ETP)* series has been informing the global energy and environment debate since 2006. Meeting the policy goals of energy security, economic development and environmental sustainability can only be achieved through energy technology development and innovation. Understanding the opportunities and challenges associated with existing, new and emerging energy technologies is critical to improving policy making to meet those goals.

A cleaner and more secure energy sector requires the rapid uptake and use of a wide range of technologies, some of which are still at an early stage of commercial development or deployment, or still at the prototype stage. But technological change takes time: for example, solar photovoltaics (PV) and batteries took decades to be commercialised and become economically competitive. Moreover the evolution of existing and emerging technologies in terms of technical performance and cost is inherently uncertain – the success of PV and batteries was far from assured when they were developed and launched – and that uncertainty increases as we peer further into the future.

The primary purpose of this edition of the *ETP* is to help decision makers in government and industry to meet the challenges of a cost-effective transition to a clean energy system with net-zero emissions, while enhancing energy security and ensuring access to modern energy services for all. *ETP* has evolved to improve its usefulness and relevance; it focuses throughout on exploring the opportunities and risks that surround the scaling up of clean energy technologies in the years ahead. It sets out where the key technologies stand today, their potential for wider deployment to meet energy policy goals, and the opportunities for and barriers to developing selected new technologies in the coming decades. It also looks at how past experiences can help governments design more effective policies to encourage innovation from research and development to market deployment. In addition, using a systems approach it looks at what governments and stakeholders need to do to accelerate the development and deployment of clean energy technologies with a particular focus on those that address multiple policy objectives.

What we mean by clean energy technology

Energy technology refers to the combination of hardware, techniques, skills, methods and processes used in the production of energy and the provision of energy services, i.e. the way we go about producing, transforming, storing, transporting and using energy. It follows that technological change in the energy sector refers to

changes over time in the types of technology that are used at various stages of the energy supply chain. Technological progress results from investment in basic and applied research, and from the development, demonstration and commercialisation of new technologies (see Chapter 6 for a detailed discussion of this innovation process and how to accelerate it).

Clean energy technology comprises those technologies that result in minimal or zero emissions of carbon dioxide (CO_2) and pollutants. For the purposes of this report, clean energy technology refers to low-carbon technologies which do not involve the production or transformation of fossil fuels – coal, oil and natural gas – unless they are accompanied by carbon capture, utilisation and storage and other anti-pollution measures.

The International Energy Agency (IEA) defines low-carbon energy technologies as: renewable energy sources (renewables[1]), nuclear power; carbon capture, utilisation and storage (CCUS); hydrogen derived from low-carbon energy sources; technologies that improve the efficiency of energy transformation (e.g. switching from incandescent to light-emitting diode [LED] lighting); other non-fossil power and storage options; and cross-cutting technologies that result in minimal emissions of CO_2 and pollution. Clean energy sources are growing in importance, but they still account for only around one-fifth of energy supply worldwide. In other words, the energy system in its present state is unsustainable.

Scope and analytical approach

The analysis in this report is underpinned by global projections of clean energy technologies derived from the IEA's in-house *ETP* model, a quantitative framework composed of four interlinked modules covering energy supply (production and transformation), and energy use in the buildings, industry and transport sectors (see online documentation of the ETP Model).[2] Depending on the sector, the modelling framework includes 28 to 40 world regions or countries. The projection period in this report is 2019 to 2070 – ten years beyond the end-point of the previous *ETP* in 2017. The most recent year of complete historical data is 2019, though preliminary data are available for some countries and sectors for the first-quarter of 2020 which accordingly have been used to adjust the projections.

We employ two scenarios to describe possible energy technology pathways over the next half century. The **Sustainable Development Scenario** – the focus in this report – sets out the major changes that would be required to reach the key energy-related

[1] Renewables include bioenergy, though this energy source is sometimes used unsustainably (e.g. if not entirely replaced with replanted biomass) and in an unhealthy manner (e.g. the indoor use of wood for cooking on an open stove).

[2] www.iea.org/reports/energy-technology-perspectives-2020/etp-model.

goals of the United Nations Sustainable Development Agenda, including an early peak and rapid subsequent reductions in emissions in line with the Paris Agreement, universal access to modern energy by 2030 and a dramatic reduction in energy-related air pollution. The trajectory for emissions in the Sustainable Development Scenario is consistent with reaching global net-zero CO_2 emissions by around 2070.[3] The **Stated Policies Scenario** takes into account energy- and climate-related policy commitments already made or announced by countries, including the Nationally Determined Contributions under the Paris Agreement. The Stated Policies Scenario provides a baseline from which we assess the additional policy actions and measures needed to achieve the key energy and environmental objectives incorporated in the Sustainable Development Scenario.

Neither scenario should be considered a prediction or forecast. Rather the scenarios offer valuable insights of the impacts and trade-offs of different technology choices and policy targets and provides a quantitative approach to support decision making in the energy sector and strategic guidance on technology choices for governments and stakeholders. The *ETP* scenarios are broadly consistent with those presented in the 2019 edition of the IEA's flagship publication, *World Energy Outlook (WEO)*[4], however the time horizon is extended to 2070 to underpin a more technology focussed view of the energy system. As well, the *ETP* scenarios incorporate updated assumptions for gross domestic product (GDP) and energy prices which have been affected with the outbreak of the global Covid-19 pandemic.

This report draws on strategic discussions during an *ETP-2020* consultation meeting with high-level energy officials and experts from government, industry, financial institutions, academia and international organisations on 3 July 2019. In addition from insights, feedback and data obtained at two high-level workshops that the IEA organised in Paris on accelerating energy innovation (18 December 2019) and carbon capture, utilisation and storage (5 February 2020).[5] It also draws on information and views provided by those who work on the IEA's broad portfolio of Technology Collaboration Programmes, which bring together more than 6 000 experts from key companies and research institutions in 53 countries in order to accelerate energy technology innovation.

[3] An additional Faster Innovation Case in Chapter 6 explores the technology innovation needs for reaching net-zero emissions already in 2050.

[4] *WEO-2019* (IEA, 2019) was released in November 2019. For more details, see: www.iea.org/topics/world-energy-outlook.

[5] Information about these events can be found at www.iea.org/weo/events.

Structure of the *ETP-2020*

Chapter 1 reviews the current status of clean energy technologies worldwide and puts the challenges ahead in context, setting out the urgent need to reduce emissions and improve air quality, assessing historic trends in energy technology and discussing the possible implications of the Covid-19 crisis for clean energy technology. It also assesses projected CO_2 emissions from existing energy assets, and their implications for long-term global emissions reductions.

Chapter 2 sets out the key projections for energy and CO_2 emissions in the Sustainable Development Scenario and describes how the energy sector will need to change relative to current trends in order to meet the energy-related United Nations Sustainable Development Goals. It details the technology pathways required to meet those goals, the central role that technologies such as electrification, hydrogen, CCUS and bioenergy could play in the energy transition to net-zero emissions and the current state of readiness of those technologies.

Chapter 3 provides a detailed overview of the technology opportunities in each energy sector stem for the transition to net-zero emissions. It sets out the structural changes required in the industry, transport and buildings sectors together with the developments needed to provide these end-use sectors with low-carbon fuels.

Chapters 4 and 5 delve more deeply into the technological needs in selected energy end-use sectors, sometimes referred to as "hard-to-abate", where cutting emissions substantially is likely to prove particularly difficult because technological solutions do not yet exist or are relatively costly. Many of these are in heavy industry (chemicals, steel and cement) and long-distance transport (maritime shipping, aviation and long-haul trucking). Both chapters identify the technological opportunities, costs and trade-offs involved in the selected areas to achieve net-zero emissions for the energy sector as a whole.

Chapter 6 takes a broad look at energy innovation, pinning down innovation needs in the Sustainable Development Scenario and assessing them relative to progress to date on clean energy innovation. It explores past experiences in bringing new energy technologies to market, identifies potential additional opportunities and looks at strategies for accelerating innovation in clean energy technology. We consider the potential of innovation to support a clean energy transition to net-zero emissions by 2050 in the Faster Innovation Case, which amongst others includes consideration of technologies that are today in the very early stages of development.

Chapter 7 sets out key recommendations for the development of long-term clean energy transition plans, including recommendations dealing with the management of existing CO_2-intensive energy assets, the creation of markets for clean energy technologies at an early stage of adoption, the development of priorities for new clean energy infrastructure and for the development and demonstration of clean energy technologies.