THE ENERGY TRANSFORMATION SCENARIOS

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FOREWORD

BY BEN VAN BEURDEN, CEO

It is a privilege of my job that I work with the scenarios team as much as I do. They are a group of economists, energy experts, political analysts and big thinkers who, together, provide both short-term insights and possible versions of the future stretching decades ahead.[1] It is the core task of the scenarios team to challenge accepted ways of thinking. In doing so, they help Shell to see around corners, to anticipate bumps in the road and to expect the unexpected.

Naturally they cannot predict the future in granular detail, nor are they tied down in the thinking of the present day. That helps us make sense of what is happening in the world, and to make better, more resilient and potentially transformational decisions.

Much of the team's work is never seen outside of Shell. They are busy applying their expertise and intelligence to the business challenges Shell faces. That is why I always look forward to each publication from the scenarios team: it is a chance for us to widely share the sort of thinking and the perspectives that they produce. We always publish in the hope these perspectives help governments, academia and other businesses to better understand the possibilities and uncertainties ahead. Within these pages there are insights into the future of energy, of course, and also into the choices facing our world today and the possible consequences.

> Shell intends to play its part and help society to succeed. And success means having a healthy planet, as well as people able to enjoy better lives.

So, as you read this report, I would like to ask you to keep one thing in mind: each of the three futures set out here is possible, but only one of them presents a truly desirable destination. **Sky 1.5** is that scenario. It imagines a world which has achieved the stretch goal of the Paris Agreement to limit global warming to under 1.5 degrees Celsius this century. **Sky 1.5** is a description of how the world can succeed, even starting from where society is today, against the backdrop of a pandemic and with global greenhouse gas emissions still trending upwards.

Sky 1.5 is a highly ambitious pathway that is still technically possible but extremely challenging. Time is running out for the world to start along it, but Shell is determined to help. We aim to serve our customers as they follow their own carbon dioxide (CO_2) reduction pathway, helping them to do so and providing the low- and zero-carbon energy solutions they want.

Shell has become the organisation it is today by evolving with the energy system. Today, that system is dominated by coal, oil and natural gas. But evolution does not stop, and nor will the change at Shell. We see the decarbonisation of the world as the only right way forward for the health of the planet. As a business, we also see global decarbonisation as an opportunity: a chance to grow as we evolve.

Sky 1.5 requires pioneers across all parts of society to push things forward: pioneering leaders, countries and businesses. Shell intends to play its part and help society to succeed. And success means having a healthy planet, as well as people able to enjoy better lives.

Thank you for taking the time to explore these pages. I hope you gain new perspectives into possible futures for our world. I also hope you enjoy your time with the work of the scenarios team every bit as much as I do.

JEREMY BENTHAM,
HEAD OF SHELL SCENARIOS

INTRODUCTION: HOPE, CAUTION AND ACTION

Scenarios and the scenario mindset are important aspects of learning in Shell. They have been nurtured and applied within the organisation for more than five decades as a useful tool for exploring future possibilities, so that Shell can make its own choices as resilient and wise as possible. In this report, the Shell Scenarios team is sharing its latest long-horizon scenarios and the insights it has drawn. We hope these are a helpful contribution as the world grapples with difficult choices ahead.

Hope and caution

Shell recently supported work with the MIT Joint Program on the Science and Policy of Global Change on a report that carefully considers CO_2 emissions-reduction trends and actions that are likely in the future, even in the absence of a globally coordinated mitigation effort. The report offers both hope and caution.

> “The ability to learn faster than your competitors may be the only sustainable competitive advantage.”
>
> **Arie de Geus**, author and former head, Shell Strategic Planning; Harvard Business Review, March 1988

GROWING PRESSURES – THE INEVITABLE TRANSITION

A widespread assumption about the energy system is that it will remain static and that decades will pass with emissions at current levels or even increasing as more coal is used in developing economies, more oil is used for transport, and more gas is used for heat and power. This assumption leads to the view that 4, 5 or even 6°C of warming will occur. However, the reality is that a confluence of pressures is driving change, underpinned by the physical reality of a changing climate. These growing pressures play out in all future scenarios, although in different ways and at different paces:

The climate changes

- Global surface temperature continues to rise, and impacts become more apparent.
- Sea level continues to rise with visible consequences.

Activism rises

- Voters pressure cities, states and countries to develop green policies.
- Shareholders push companies to take on net-zero emission goals and targets.

Local and national governments act

- Ongoing actions under the United Nations Framework Convention on Climate Change (UNFCC) and the Paris Agreement drive ongoing action, with the emergence of net-zero emissions (NZE) as a framing concept.
- Incentives and mandates drive down the cost of new energy technologies and lead to further uptake.
- Large NZE policy frameworks (for example, in the EU and Calfornia) are established and new NZE policy frameworks (e.g. China) begin to emerge.

Technology develops

- Renewable energy access becomes cheaper.
- New developments in physics, chemistry and materials science emerge (for example, photovoltaics and energy storage).
- Digitalisation of society rapidly increases.

Markets evolve

- Financial markets distance themselves from fossil fuel investments, particularly coal.
- Climate-related financial disclosures bring transparency.
- Businesses and consumers demand lower-carbon footprint products and are prepared to pay for them.
- Markets develop to support low-carbon investment (for example, nature-based solutions).
- Alternatives to coal, oil and gas become increasingly competitive.

Massachusetts Institute of Technology (MIT) with support from Shell created a scenario exploring the impact of these growing pressures, even if they are not decisively accelerated. This Growing Pressures scenario shows a central outcome below 3°C of average surface temperature warming, which is higher than the goal of the Paris Agreement, but considerably lower than many widely used no-policy scenarios. The MIT scenario also highlights the actions required to achieve an improved outcome. Section three of this report focuses on realising such improved outcomes and meeting the goal of the Paris Agreement.

The MIT report offers hope in showing that technological and policy advances have already happened to the extent that the direction of travel is shifting away from traditional fuels like oil, natural gas and coal and that some of the world is now embarking on pathways towards net-zero emissions.

The caution is that, globally, society is not yet moving down these pathways fast enough to meet the Paris goal of limiting global warming to well below 2°C.[2] The world and its leaders, however, cannot give up on making the difficult choices that could speed up the transition.

Nevertheless, the COVID-19 pandemic has created disruption, which could break up old ways of thinking and perhaps accelerate progress along the pathways to Paris.

While people are amazingly adaptable and quick to view changed circumstances as normal, the world is still in crisis. The global pandemic, which has led to a deep economic recession, has occurred alongside the slower, but no less concerning, increase in the pace of climate change.

The pandemic is a crisis. And, yet, there are still choices: the ancient Greek word "krisis", from which crisis derives, means decision. Societies can decide to create opportunities from this crisis that could lead to a new future of human well-being and a more sustainable energy system. Coupled with the challenges presented by meeting the world's energy needs while also addressing urgent climate change concerns, the coronavirus pandemic could open a way forward to transforming the world's energy system.

The Energy Transformation Scenarios

This report explores three long-horizon scenarios – **Waves**, **Islands** and **Sky 1.5**. All are possible pathways towards the future that have both attractive and challenging features. But of the three, only **Sky 1.5** has a pace and timing for energy decarbonisation that is fast enough to limit global warming to 1.5°C above pre-industrial levels by the end of this century.

Sky 1.5 is solidly built on lessons learned from previous energy transitions. During the past few decades, however, the pace of change in the policies and practices shaping the energy system has been relatively modest – the pace needed now must be faster and will be extraordinarily challenging. It requires practical actions to speed the mass deployment of cleaner technologies, to motivate new behaviours and investment choices and to remove emissions. New alignments, smart policies and pioneer leaders can accelerate this action.

> ...the COVID-19 pandemic has created disruption, which could break up old ways of thinking and perhaps accelerate progress along the pathways to Paris.

> Sociopolitical choices affecting the shape of the economy, the energy system and the environment that are being made now will be significant for decades to come.

THE ENERGY TRANSFORMATION SCENARIOS: FOUR CONCLUSIONS

1. Energy needs will grow.

- A better life for all requires sufficient energy to provide everyone with a decent quality of life.[3]
- The energy needs of growing populations seeking a decent quality of life will outstrip the significant capacity to improve energy efficiency.
- A healthy planet requires a transition of the energy system from one that relies primarily on fossil fuels to one that increasingly uses sustainable sources of energy to achieve net-zero emissions.[4]

2. The energy system will be transformed – the issue is speed.

- To meet all energy needs while decarbonising will require accelerating electrification of the economy through renewable power and will also still require the use of liquid and gaseous fuels in sectors that are hard to electrify; at the same time, these fuels will steadily transition from traditional fossil fuels to low- and no-carbon sources as end-use technologies evolve.
- Such energy transitions are inevitable over time, but they will proceed at different paces in different places and in different sectors.
- Sociopolitical choices affecting the shape of the economy, the energy system and the environment that are being made now will be significant for decades to come. Making these choices could be the most challenging part of energy transitions.

3. Transformation will have costs and benefits.

- Taking steps towards the goal of the Paris Agreement could be rewarding both economically and environmentally, although the necessary actions involve costs.
- These overall societal costs of investing in energy transitions are expected to be manageable.
- Triggers like the current COVID-19 crisis provide opportunities to transform traditional approaches and apply new ones that are better tuned to the urgent needs ahead.

4. Action accelerators are necessary to meet climate aspirations.

- Society is not currently on course to meet the goal of the Paris Agreement.
- With sufficient acceleration along known pathways, it nevertheless remains technically possible, although extremely challenging, to achieve these climate aspirations.
- Three fundamental action accelerators are needed for a timely and just transition to make Paris happen: alignments of policies, sectors and governments; smart policy rules and incentives; and pioneer leaders.

SCENARIO SUMMARIES

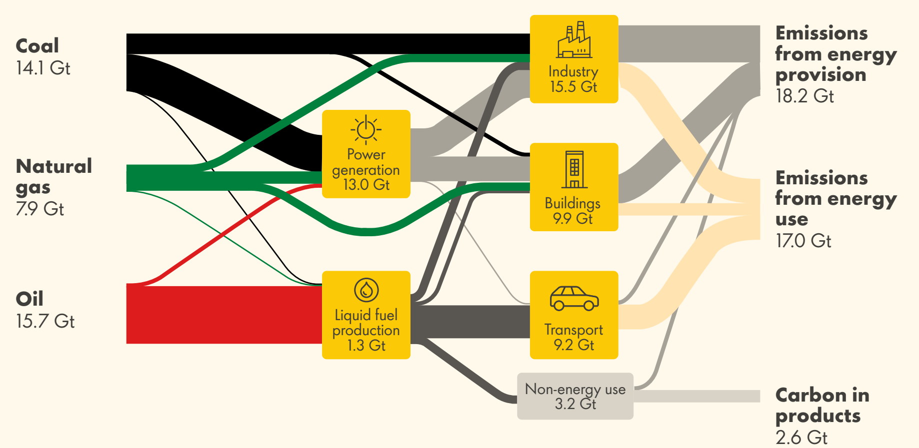
The Energy Transformation Scenarios – **Waves**, **Islands** and **Sky 1.5** – begins with three stories that explore different initial recovery responses to the crises of 2020 and how these responses develop into future pathways throughout the 2020s and beyond. *Scenario Energy Landscapes: A Graphic Exploration* goes deeper into the significance of the scenarios for the energy system by quantifying and comparing the different energy and environmental implications of the choices taken in each world.

In **Waves**, the initial response to the crises of 2020 is to repair the economy – *wealth* first. Other underlying societal and environmental pressures receive less attention initially until their relative neglect provokes backlash reactions. Then, moving quickly, but starting later than required to meet the goal of the Paris Agreement, global society achieves an energy system with net-zero emissions – *late, but fast, decarbonisation*.

In **Islands**, governments and societies decide to focus on their own *security*, with a new emphasis on nationalism threatening to unravel the post-war geopolitical order. Although the normal course of equipment and infrastructure replacement and the deployment of cleaner technologies bring progress and eventually net-zero emissions, the world overshoots the timeline and does not achieve the goal of the Paris agreement – *late and slow decarbonisation*.

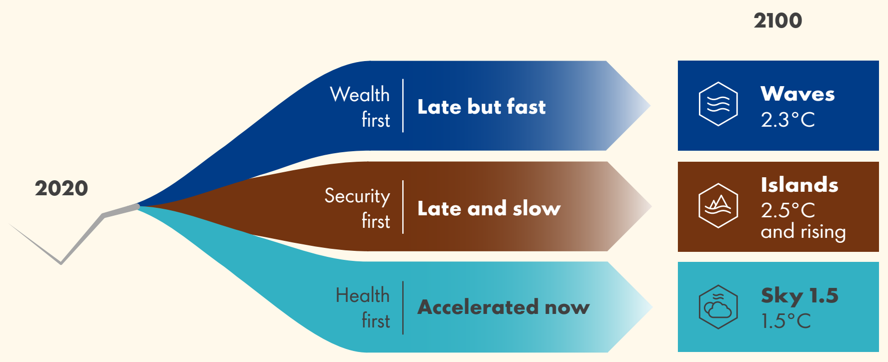
In **Sky 1.5**,[5] the initial response to the crises of 2020 is to focus on responding to the pandemic and related challenges to public well-being – *health* first. Lessons learned from shared best practices, alignments of diverse interests and institutional improvements help create a pathway to the health not only of people and society, but also of the environment, including meeting the stretch goal of the Paris Agreement – *accelerated decarbonisation now*.

Figure 1: Energy-related CO_2 emissions today and the key areas to be transformed



Source: Shell analysis based on 2019 data

Figure 2: Pace of decarbonisation in the three scenarios



Source: Shell analysis, MIT Joint Program on Global Change

Waves and **Islands** are traditional scenarios in that they explore future possible worlds without any specific focus on creating a desired outcome. **Sky 1.5** also explores a future possible world, but one that is aspirational as well as being rooted in today's realities. In the spirit of the original **Sky** scenario published in 2018, **Sky 1.5** maps the difficult pathway society would need to take to meet the stretched climate goal of the Paris Agreement to limit global average warming to 1.5°C above pre-industrial levels by the end of this century.

Society has not moved fast enough since 2018 to be on the **Sky** pathway. Nevertheless, the current crises provide potential opportunities to choose to make faster progress. Fundamentally, all the major challenges are rooted in making these choices fast enough to secure the desired outcomes. **Sky 1.5** addresses these enormous challenges.

Starting from the reality of energy-related emissions today (Figure 1), what are the critical decision points along the path to **Sky 1.5**? What choices could society make – or fail to make – that will shape the quality of life for the months, years and decades to come? What could galvanise enough sectors of the global economy and members of the global community to *act*? Section three of this report explores these questions further.

> "In **Sky 1.5**, the initial response to the crises of 2020 is to focus on responding to the pandemic and related challenges to public well-being – *health* first."

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SECTION ONE

RECOVERY, RESILIENCE AND TRANSFORMATION

The COVID-19 pandemic has generated significant turning points, with shifts across almost all societies and economies. It has exposed tensions and weaknesses in the global systems – but also shifted policy and behaviour in ways that open new possibilities for the future.

RECOVERY

The most significant realisation is that the world will not return to the way it was before COVID-19. One way or another, the world will be living with the coronavirus and its implications for the next decade and with the impact of its sociopolitical and economic disruptions for even longer.

Most people and societies are seeking to recover from the deep shocks to ways of living caused by the global pandemic and its economic consequences. People have been affected in many ways, and so there are different recovery responses. For those who are vulnerable, good health will be foremost. For others, it will mean getting back to work, or opening schools, or travelling.

In broad terms, we have characterised the objectives of *recovery* at the front of people's minds as the recovery of *economic strength*, the recovery of a sense of *security* and the recovery of a sense of *well-being*. These different objectives form the driving forces behind the scenarios in this report. To some extent, all societies will be seeking all three goals – material prosperity, security and health – but different circumstances and values will make one or another a greater priority in the mix.

RESILIENCE

Over time, attention will turn from short-term *recovery* to long-term *resilience*. Resilience is the capacity to survive, adapt and grow in the face of change and uncertainty.

Resilience is necessary for the survival of any complex system – a human being, a company, a sector, a city, a country. It is independent of ethics – for example, a drug cartel can be very resilient, and both democratic and authoritarian forms of government can be resilient in a narrow sense. More resilience, in other words, does not necessarily serve the long-term interests of society.

> "It is not the strongest of the species that survives, nor the most intelligent. It is the one that is most adaptable to change."
>
> **From Darwin's Origin of Species, paraphrased.**

> *...transformative resilience* [is] the ability to transition deeply to thrive in new circumstances, as characterised by cultures of experimentation, innovation and foresight.

Complex systems exhibit three types of resilience.[6] The first of these is *structural resilience*, or the basic ability to withstand sudden shocks, which is characterised by features such as buffers, redundancy or modularity. The second is *integrative resilience*, or the ability to address systemic stresses, which is characterised by an awareness of the connections between systems at multiple scales and the importance of social capital to enable collective action. The third is *transformative resilience*, or the ability to transition deeply to thrive in new circumstances, as characterised by cultures of experimentation, innovation and foresight.

TRANSFORMATION

To achieve change, a temporary reduction of structural resilience may be needed. The current crisis may, therefore, provide a window of opportunity for the deep changes characteristic of *transformative resilience*.

The coronavirus pandemic has required an unprecedented worldwide scientific, medical and pharmaceutical industry response, including through intensive international scientific cooperation (as well as a fair amount of rivalry). Resilient responses have been forged in the crucible of the most extreme public health and economic crises in a century. Can this positive example be extended to other areas of society? Or will nations, businesses and individuals follow paths of least resistance in an attempt to return to normal?

Transforming the global energy system will involve many different types of organisation engaging with the future, supporting cultures of learning and experimentation and building transparent, inclusive, widely accepted and accountable institutions and systems of cooperation and governance.

GLOBAL SOCIETY IN TRANSITION

As they become more interconnected, people throughout the world experience more rapid change. The forces that drive these changes are themselves always shifting, but seven interconnected social transitions are already important to the energy transformation and were considered in the development of these scenarios.

Intergenerational shifts

The young have suffered disproportionate impacts of COVID-19 job losses and education disruptions, and many are seeking new political forms and more economic equality. As younger generations become more politically active, they are increasing attention on climate change, which they perceive will affect them more than earlier generations.

Digitalisation, artificial intelligence and social media

In an interconnected world, where sources of information are no longer centralised and where public opinion can be galvanised almost effortlessly, disruption is more frequent and intense. But so too is the possibility of cooperation, as can be seen in the formation of minilaterals – small, trust-based networks with a shared set of values oriented around innovation and the creation and sharing of knowledge. Digital Nations, for example, uses digital culture, practices, processes and technologies as tools to advance peer learning, support and cooperation between governments.[7]

GLOBAL SOCIETY IN TRANSITION (CONTINUED...)

Green New Deals

In responding to the economic impact of the pandemic, lessons are being drawn from the hard evidence that well-directed green investment is good for jobs and economic recovery, much like President Roosevelt's New Deal of the 1930s in the USA. The emphasis in these developments is as much on the domestic economic stimulus derived from attention to cleaner technologies as it is on the environmental benefits.

Populism

Some popular political leaders have encouraged scepticism about addressing the global climate agenda as part of their appeal to constituencies concerned primarily with domestic employment and distrustful of changes that are portrayed as costs rather than investments and opportunities. Part of the appeal of populism is its promise to return to an era of greater stability and protection from problems appearing to come from others.

Racial and other justice movements

"Black Lives Matter" and the "Me Too" movement are among several social movements across the globe focusing on equality and human rights. In many cases, protests have resulted in a reconsideration of historical figures, as well as increasing representation of minority groups in politics and entertainment. For a number of younger people, especially, justice is seen as necessary for the earth, too.

Women's empowerment

Not only are women often the most vulnerable members of society and the most exposed to the negative effects of climate change, as they gain more influence, they have often demonstrated a greater tendency to seek collaborative approaches to common problems and opportunities. In addition, rising population puts stresses on the environment – but where women are educated and have full access to reproductive healthcare, the birth rate goes down. Some analyses suggest that with these two reforms, global population could peak mid-century and return to similar levels as today by 2100. A global population of around 7 billion rather than the UN mid-case expectation of almost 11 billion would substantially reduce pressures on energy demand and the environment, including greenhouse gas emissions.[8]

Pressures on land

Growing populations, urbanisation and climate shifts are already increasing pressure on agriculture, as are dietary shifts as poorer people become more prosperous and eat more meat. The need to end deforestation and promote reforestation and rewilding to address biodiversity loss and climate change will add to these pressures on land. Harvesting diffuse energy sources like solar, wind and biomass also requires significant land use. Given both the high economic and emotional importance of land for many people, tensions are bound to keep emerging unless they are actively addressed in advance.

> "Given both the high economic and emotional importance of land for many people, tensions are bound to keep emerging unless they are actively addressed in advance."

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SECTION TWO

THE SCENARIOS

WAVES

THE 2020s – *WEALTH* FIRST

In **Waves**, the initial response to the crises of 2020 is to repair the economy – *wealth* first. Throughout repeated waves of rising and falling illness and death, the emphasis on immediate economic recovery reflects a widespread wish to return to the status quo. Self-interest is largely perceived in economic terms, and resilience is judged in terms of economic strength. Economic recovery is fairly rapid, but despite the apparent robustness of gross domestic product (GDP) figures and financial markets, growing inequality tells a different story. The numbers are doing better than the people those numbers represent.

In spite of the mortality rates from COVID-19, the fear of the virus fades relatively quickly. Vaccines are widely distributed in most advanced economies by mid-2021, and even where vaccine availability is low, most societies adapt to life with COVID and implement effective mechanisms to monitor, track and isolate the virus.

Competing giants

Waves is a world of competing economic interests and alliances. China continues to expand its influence by establishing business and cultural outposts across the world, from railroads in Africa to cultural centres in the Caribbean. Its growing IT and cleaner technology businesses outpace the USA, especially in relation to 5G, where most of the world adopts more affordable Chinese technology. While both the USA and China are focused on restoring growth, they also compete for the European market, and Europe aligns its trade policies sometimes with China and sometimes with the USA to suit its short-term interests.

Driven by changing market forces, the old post-World War 2 alliances slowly erode, and what had once seemed an inevitable increase in structural reforms and collaboration now seems uncertain at best. Structural changes under way before the pandemic slow, and international cooperation weakens, with only the agreements underpinning short-run economic performance taking priority. The COVID-19 crisis, despite all its upheavals, fails to fundamentally reset domestic policies and international cooperation.

The business imperative

While the economic shock from the pandemic rages, using stimulus funds for recovery without regard to energy transitions means not taking the risk to build new or innovative businesses for the future. Weaker businesses disappear, but no major transitions emerge in the structure of the economy.

Governments encourage a return to normality, including to pre-pandemic employment levels, but the highest priority for recovering businesses is efficiency and cost-cutting. It is a business-driven world, with productivity growth resulting not only from new efficiencies but also through huge post-pandemic private-sector investment and digitalisation of the economy.

A layered economy

While GDP and financial markets recover relatively quickly, not as much progress is made across all levels of society. Short-term policies focus on stimulating economic growth, leaving structural weaknesses unaddressed.

Insufficient attention is given to investments in people and their capabilities, including education and retraining post-COVID-19.

The top layer of society recovers fastest because the richest have not lost much money – and some have even benefitted; the middle class shrinks, as many people in both rich and poor countries lose income and jobs and drop into a lower, poorer layer. In addition, people who were briefly hailed as key workers during the pandemic still find themselves in precarious low-paid positions.

On the surface, it looks as if the economy is going back to normal, with the pre-pandemic industries starting up again. But underneath, many businesses have undergone restructuring. In some, for example, workers have proved to be more productive when working from home, so some companies downsize offices. Other companies, which have laid off workers, hire fewer when business picks up. And the greater threat to worker security – automation – has continued replacing what were formerly considered secure jobs.

> “In **Waves**, the pandemic has exposed and even increased inequalities that had been growing in many countries all along.”

BEYOND GDP

Gross domestic product continues to be the most accepted measure of economic performance and growth, but it does not recognise that for decades, and increasingly today, there is equal and sometimes more value placed on less quantifiable aspects of well-being.

> “*The gross national product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials.*
>
> *It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country, it measures everything in short, except that which makes life worthwhile.*”
> **Robert Kennedy, 1968**

> “*GDP tells you nothing about sustainability.*”
> **Nobel Prize-winning economist Joseph Stiglitz, 2008**

> “*Nothing is more destructive than the gap between people’s perceptions of their own day-to-day economic well-being and what politicians and statisticians are telling them about the economy.*”
> **French president Nicolas Sarkozy, 2009**

> “*We must learn new ways to define the concept of growth for the 21st century.*”
> **German chancellor Angela Merkel, 2010**

> “*Progress measured by a single measuring rod, the GNP, has contributed significantly to exacerbate the inequalities of income distribution.*”
> **Robert McNamara, President of the World Bank, 1973**

In **Waves**, the pandemic has exposed and even increased inequalities that had been growing in many countries all along. Advanced economies have demonstrated strong structural resilience – but just below the surface, the resentment of those left behind is increasing, feeding into identity politics and social discontent. In many societies, by the 2030s there is a growing sense that all is not well.

Growth and energy demand

Before the pandemic, many emerging Asian economies were poised to lift off into a period of rapid growth. During the 2020s, these countries focus on the struggle to reassume their lift-off positions – and by 2030, most have. The immediate effect of this push is an increase in energy demand, including for coal and oil and especially for gas. While some developed economies are making good progress in the introduction of electric vehicles and the subsequent reduction of greenhouse gas emissions from their light transport sectors, this progress towards lowering fossil fuel use is more than offset by strong growth in emerging economies and in other countries where transitions conventionally lag.

This strong growth allows OPEC countries to invest in oil production growth and economic diversification – but diversification does not happen up to the level required to thrive in the 2040s and beyond, when the demand for oil changes abruptly. Russia, meanwhile, pushes to maintain its oil output and to increase its gas production and is late to join the efforts to increase the speed of the energy transition. Globally high prices keep the incentives in place for businesses in the USA and Canada to continue exporting oil, even though social and political pressures in both countries are trending towards greener economies.

Climate change, rising energy prices and public pressure

During the early 2020s, energy transition is not as fast as it needs to be to meet the Paris goal, mainly because so much focus and so many resources are devoted to getting the pandemic under control and the economy back on track.

While low-carbon technologies that are already cost-competitive continue to advance, there is no coherent focus beyond domestic economic choices. Declared climate intentions and soft policy mechanisms prove weak, and even existing legislated policy like the EU Emissions Trading System is eventually overridden. Deployment of new technologies is insufficient to keep up with the rapid decline of the legislated cap for allowed emissions; it proves a crushing constraint for EU industry working hard to recover after COVID-19, so more allowances are allowed into the system, effectively weakening it.

But toward the end of the 2020s, when climate change effects are increasingly felt in all economies, the public begins to react to more frequent and more extreme weather events.

The lack of previous attention to structural issues ranging from social welfare to climate change is blamed for the societal and environmental stresses experienced. Populist movements rise up in response to income inequality and the steadily rising prices for energy, while climate-conscious citizens also begin to channel their anger and resentment into action. Politicised objectives are increasingly pursued through climate activism that could take many forms, as frustration with regular political processes mounts. A stronger awareness develops regarding the practical changes required to reduce emissions and the consequences of weak government and international institutional capacity.

Pathways towards Paris – alone and "alone together"

Different countries respond to the challenge of climate change at very different paces. While some force through trade agreements that include export embargoes on technologies associated with high emissions, or impose carbon border adjustments to keep out "dirty" imports, others enable regional technology deployment, and still others respond with knee-jerk policies. Some countries and sectors pursue radical solutions to tackle climate change, but others fail to turn their good intentions into action.

Many emerging economies still focus on shorter-term socioeconomic policy agendas, which continue to be of more immediate concern than global issues such as reducing greenhouse gas emissions. Nevertheless, the growing cost of fuel and fuel subsidies is particularly challenging and helps to encourage the incremental diffusion of increasingly cost-competitive cleaner technologies like power generation from solar and wind energy.

A few leading economies and some subnational entities, such as states and cities, move forward for different reasons to meet the aspiration of net-zero emissions by 2050. In effect, they stand "alone together". Even without an explicit cooperative framework for action, these governments stimulate new technology, create enabling regulatory frameworks and infrastructure and set stringent mandates.

Progress is made, but in waves, not in a steady flow, and these periods of slowdown mean that the hope of meeting the Paris goal recedes.

The decline of fossil fuels

By 2030, renewables have become cost-competitive to the extent that coal demand begins to fall, even as energy demand itself is rising. Societal pushback against fossil fuels, particularly focused on international oil companies, leads to independent and national oil companies increasingly satisfying commodity oil demand. The percentage of oil produced by international oil majors, which was just under 15%[9] in 2020, declines further. Companies are beginning to shift investment towards gas, while focusing growth on low- and no-carbon energies. Global competition for big energy ensues between the international oil companies, tech giants and fast-growing renewables companies.

Initially, the earlier periods of weak investment in new oil projects from 2015-25[10] lead to a period of higher oil prices as supply falls short of growing demand. Suppliers use increased revenues to fund significant growth in production. The period of continued strong growth in demand up to the late 2030s propels a wave of investments globally. Deep-water production doubles in size, while conventional oil investments maintain a production plateau and US light tight oil returns to a period of strong growth. Natural gas exports from key regions like Central Asia, North America and Russia show continued growth facilitated by past and ongoing investments in midstream infrastructure.

> "Some countries and sectors pursue radical solutions to tackle climate change, but others fail to turn their good intentions into action."

However, the additional backlash of societal and political responses to climate change lead to both natural slowdowns and enforced knee-jerk policy-driven reductions in the growth of fossil fuel demand from the later 2030s. Prices fall, and some investments struggle to make their expected returns. For companies that have been slow to react to change, the threat of stranded assets becomes real.

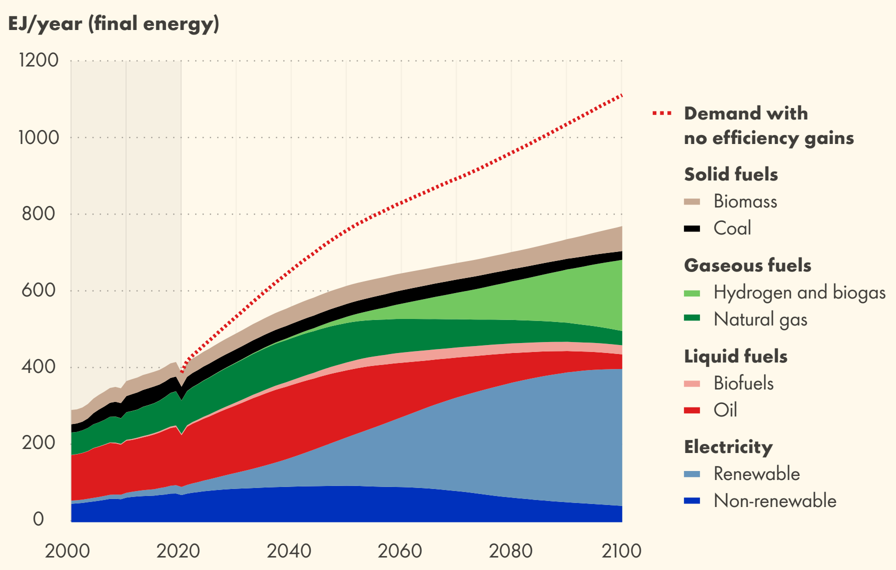
In some leading economies, deployments of new cleaner energy technologies have made them affordable. As a result, a number of emerging economies leapfrog to lower- or no-carbon technologies, such as next-generation biofuels and hydrogen. A phase-out of fossil fuels into a hydrogen economy starts in earnest by the 2040s. Attention is focused primarily on phasing out the use of fossil fuels entirely rather than mitigating some of their residual impact through carbon capture, because carbon capture, utilisation and storage (CCUS) infrastructure did not become established in the 2020s and 2030s.

Serious action to decarbonise the global energy system may have been late to start but, once started, it moves very fast. The technologies to deploy have been primed, and finance is available for investment.

A better world – but missing the Paris target

By 2050, the structure of most economies is still layered, with significant gaps between the top and bottom. But the world as a whole has become richer, so that many people on the bottom layer have risen out of absolute poverty. Despite the ongoing social and environmental challenges, it is a

Figure 3: Total final consumption of energy – **Waves** scenario



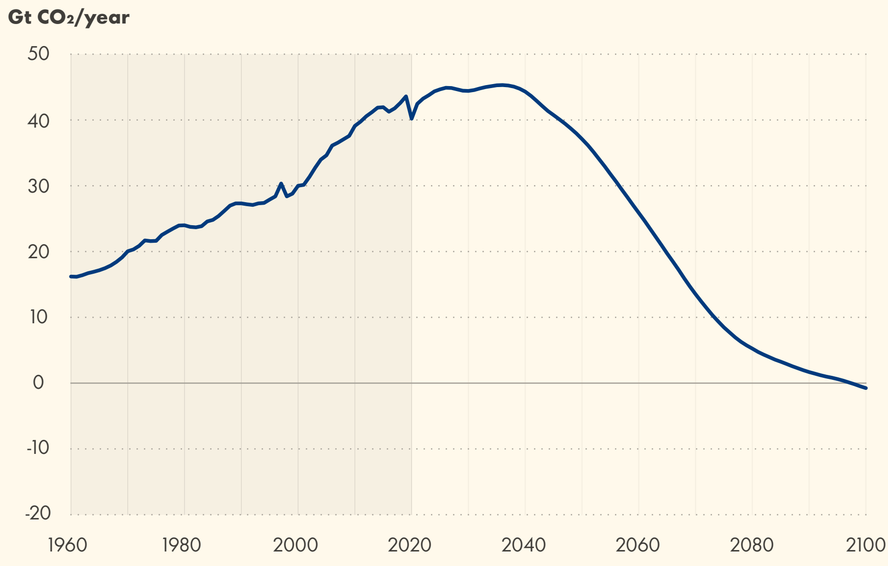
Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved better world now for many people, thanks to economic progress and other quality-of-life improvements.

From an energy perspective, renewable sources are dominant in power generation and beyond, with green hydrogen (produced by electrolysis from renewable energy) effectively displacing fossil fuel demand. Bioplastics largely reduce dependency on fossil fuels to manufacture plastic, and there is hardly any use of CCUS by the fossil fuel industry since only the most significant major resource holders are still producing oil.

An energy system with net-zero emissions is eventually achieved globally – but later than required to meet the goal of the Paris Agreement because of the delayed start of accelerated transformation. Emissions overshoot the carbon budget (Appendix 1) required to achieve the Paris goal, demanding greater adaptation to the consequences of climate change.

Having missed the Paris target means that by the end of this century the world must face long-term higher temperatures of around 2.3°C above pre-industrial levels. The alternative would be the even more difficult challenge of achieving very significant net-negative emissions over the longer-term future to restore a healthy planet – and that would require aggressive attention to withdrawing CO_2 from the atmosphere through natural methods like reforestation and perhaps even finally giving serious attention to direct air capture and biomass-enhanced carbon capture and storage. However, such an achievement would require levels of cooperation the world of **Waves** never manages to reach.

Figure 4: Total CO_2 emissions – **Waves** scenario



Source: Shell analysis, Global Carbon Project (2020)

ISLANDS

THE 2020s – *SECURITY* FIRST

In **Islands**, the initial response to the crises of 2020 is to focus on the near-term recovery at home – *security* first. In the world of **Islands**, resilience is understood as autonomy and self-sufficiency. These internally focused recovery efforts have mixed results, with some countries doing relatively well and others suffering from ineffective policies and fraying political legitimacy.

As a nationalistic islands-type mentality takes hold, growth in the global economy begins to stagnate, and efforts to address the climate challenge slow. **Islands** involves the triumph of the nation state and nationalism, while the forces behind globalisation weaken. It is a more challenging economic environment where technology innovation and its diffusion are slow, and efforts to address climate change fragment.

In most countries, there is a protracted struggle to deal with COVID-19 through lockdowns followed by a relaxation of restrictions, which leads to renewed levels of infection followed by reimposed restrictions. This stop-start muddle-through recovery frustrates citizens in those countries where policies have been most chaotic, leading to populist challenges against established elites in many of them. The countries that are most successful in controlling the virus early are either those whose governments enjoy a high level of public trust or those autocratic regimes that exercise more control over their populations. These less democratic regimes are strengthened by their success in controlling the pandemic. Those democracies that have suffered high mortality rates, however, suffer diminished trust in their governments.

Pandemic fallout

The COVID-19 pandemic eats into the nexus between trust and power, while also feeding an already growing disillusionment with globalisation. In many countries, trust in science and in democratic governance are called into question, and in others, there is a growing belief that radical change is possible and necessary in order to safeguard society. But in almost all countries, governments and people strive to secure internally focused and short-horizon objectives. This emphasis on the near-at-hand hinders the ability to learn from what is effective elsewhere. And the seemingly endless series of policy starts and reactions – first driving some economic momentum and then leading to a recessionary stop – leads to increasingly negative social, political and economic repercussions.

> ...the pandemic accelerates the shift from the previous era of international cooperation to one characterised by regionalism and nationalism...

The great disappointment is how far many democracies and most of their leaders are falling short in dealing with the crisis. A growing majority of people, especially from the younger generation, do not trust their governments to act in their interests. Rather than generating a sense of "we're all in this together", the COVID-19 pandemic accentuates social divides where politics are already polarised.

In this way, the pandemic accelerates the shift from the previous era of international cooperation to one characterised by regionalism and nationalism, with China and the USA competing for global dominance. Policymaking is focused inward. It is a world where some nations begin to profit from the stronger internal societal cohesion that is eventually established, but operate within a fragmented international context. Geopolitics are recalibrated and shift in tandem with increasing attention on national security and trade barriers. Security of energy supply and domestic socioeconomics dominate agendas.

Growing divisions

As COVID-19 vaccines become available in 2021, emerging economies are far down the list of those who receive them. The competition among countries to ensure that their citizens are among the first recipients extends to a general me-first attitude towards global trade and international institutions. Policymaking continues to be focused inward with an increasing emphasis on national boundaries.

Even within countries, the social and economic lockdowns imposed by governments have exacerbated divisions in society. The socially and economically disadvantaged, who are more likely to lack access to good healthcare and to suffer from underlying health conditions, are hit hardest by economic crisis and then by the pandemic.

Internationally too, divisions are growing, with the USA-China divide continuing to widen. China assumes an increasingly important global leadership role, especially in providing enough stability in weaker OPEC countries to ensure oil supplies. The USA turns inward, dealing

GEOPOLITICAL TENSIONS

A new geopolitical order is taking shape globally that will impact how the leading established power, the USA, and the leading challenger, China, relate to each other. How this relationship develops will necessarily shape a host of issues, including, critically, the race to reaching net-zero emissions, and will feature differently in different scenarios.

This new global order is not simply a return to a world of competing powers. Rather, it is a world where no one nation will be able to set the rules of global governance and where there is no one ideal economic or political model to which everyone aspires, but where new approaches arise. It is a world of intersecting dependencies, competitive relationships and, occasionally, confrontation.

The USA and China may confront each other in specific areas, and they will continue to compete for influence and strength. That competition could be constructive where demands for reciprocity open up opportunities and raise standards for both powers. And constructive competition could lead to alignment on specific issues of mutual interest, whether on economic growth, on technocratic developments to support international public health, or on climate action.

Even within countries, the social and economic lockdowns imposed by governments have exacerbated divisions in society.

with its internal political and cultural divisions. In the latter half of the 2020s, the weaknesses of both the USA and China become apparent, and the global geopolitical order fragments further. There are also growing tensions among EU member states, and between the EU and the USA, as US support for NATO and other security links weakens.

Economic costs and energy politics

In many countries, as policy failures compound politically driven and poorly prepared exits from lockdown, the economic costs mount. Trade wars and identity-driven politics reinforce nationalism and regionalism, which then undercut cooperation and global trade, leading to the adoption of more protectionist policies and a retreat towards security on one's own national or regional "island". As innovation, free trade and immigration slow, many economies, including the USA and China, experience a decade of disappointing economic growth. Developing countries are particularly hard hit.

Tension arises in the 2020s between the USA and its allies, as the USA competes with Russia for the European gas market in an economic environment in which the industries in neither nation have enough capital to maximise both their oil and gas potential. The USA pushes Europe to accept its liquified natural gas instead of Russian pipeline gas, but ultimately Europe needs to turn to Russia for more supply, in part because Russia has the infrastructure to grow exports to Europe. Nevertheless, the EU-Russia relationship has its own tensions in that European countries have invested much more in climate change mitigation while Russia continues to neglect it as a key issue, focusing instead on its own security concerns. Meanwhile, in the USA, growth in shale gas is on-again, off-again, reflecting pendulum swings in politics and prices. Overall, there are considerable degrees of uncertainty around how the global picture will look.

Fragmentation of the global climate movement

Slower global economic growth and decreased cooperation challenge efforts to transition to a lower-carbon economy. Trade barriers also constrain the pace and scope of international decarbonisation ambitions by increasing costs and dampening incentives to develop new cleaner technology. A few leading economies do decarbonise within their own borders and economies, but cross-border sectoral decarbonisation at scale remains a second-order priority. Innovation is focused on local problem-solving.

The pandemic-induced economic slowdown at the beginning of the decade has resulted in a slight reduction in global greenhouse gas emissions, encouraging some to hope that progress towards the Paris ambition is possible. By the late 2020s, therefore, a limited number of like-minded societies have begun to cooperate more closely, bound by pragmatic and values-driven common interests on climate and energy transition.

But these archipelagos of effort are inadequate to the challenge without greater cooperation, and the Paris process runs into serious trouble. Key countries fail to agree on which actions to take, and the energy transition lags behind the rise in global population. Coal survives for longer than expected. Even agreements already embedded in legislation begin to unravel.

Leaders in the global climate movement have limited confidence that global cooperation will materialise to mitigate against climate change. Although virtual global cooperation exists on many individual topics and specific issues, overall, a sense of global political community is absent. Instead, the remaining collective action to deal with climate change mainly takes place within national boundaries.

In low- to middle-income countries, domestic pressures for climate action are dulled by challenging economic contexts. Low oil prices in the 2020s and 2030s have resulted in a number of these countries finding themselves locked in a dependence on fossil fuels, with little incentive to spend scarce resources on new infrastructure. A few governments push the climate agenda but fail to get traction beyond local and regional collaboration. And in those few countries where mitigation efforts are made, they are not enough to make tangible reductions in carbon emissions.

The increasing turbulence in the weather, induced by climate change, is recognised and suffered by many people, but the blame is largely placed on others rather than embraced in domestic politics. Greener nations express anger towards emitting nations who, in turn, call for the original polluters – generally considered to be member countries of the Organisation for Economic Co-operation and Development (OECD) – to pay for their transition. As climate events increase, knee-jerk reactions lead to disruptive and uncoordinated policy responses.

In the later 2030s, technology improvements and innovations, enabled in large part by the support of a select few governments, help some countries address the energy transition.

> “Given economic pressures and inward-looking approaches to resilience, countries remain dependent on cheap fossil sources of energy for longer than had been hoped...”

As lower-carbon technologies become cheaper, an increasing number of countries rejoin the energy transition effort.

These technology improvements reinvigorate the archipelagos of like-minded societies. Regional collaborations and bilateral agreements to implement adaptation measures and diffuse cleaner technologies form the core of pragmatic alliances. In these alliances, key players see common interests while recognising fundamentally different values – for example, north-west Europe and China.

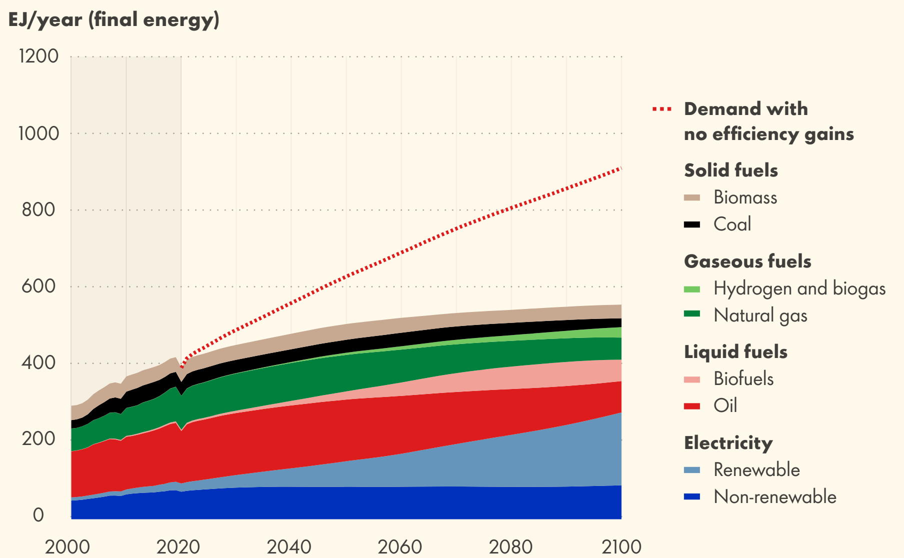
Given economic pressures and inward-looking approaches to resilience, countries remain dependent on cheap fossil sources of energy for longer than had been hoped by supporters of the Paris process. The world phases out coal more slowly until it is ultimately priced out by renewables at scale, backed by policies and new technologies that ensure security of supply. The marginal cost of oil supply eventually starts to increase. This creates an additional burden on developing economies where it is difficult to move away from a reliance on fossil fuels, because doing so requires investments in new infrastructure. Increased use of carbon capture, utilisation and storage enables continued production of oil and gas, and the world overall experiences slow demand reduction for fossil fuels and a slow energy transition.

The Paris goal – falling behind

The lack of progress in the near term means that beyond the 2050s, climate impacts become serious and, in the face of insufficient action, are expected to become even more serious towards the end of the century. Budget constraints in vulnerable countries leave few alternatives other than to restrict heavy-emitting sectors such as aviation. Unilateral mandates and caps are introduced in a belated effort to cut emissions. But they don't succeed.

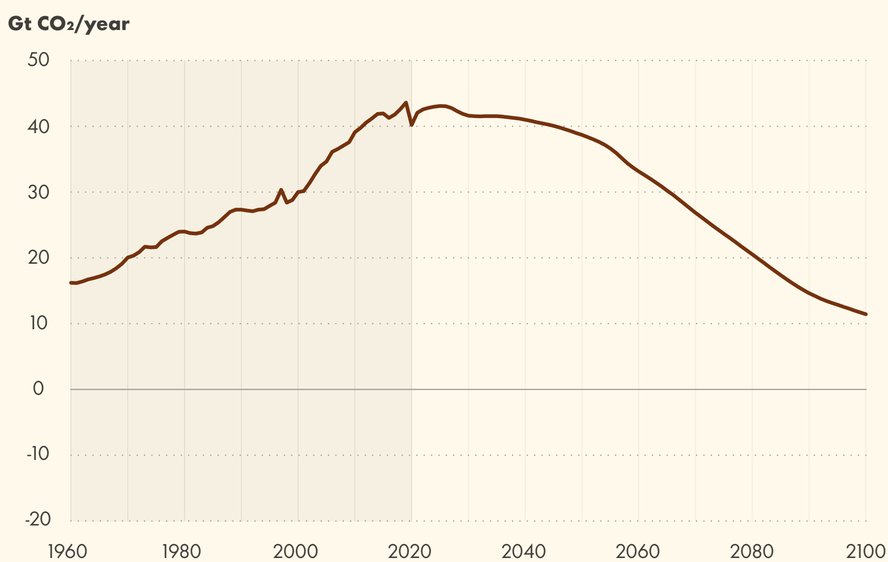
The Paris climate agreement may have restructured the overall debate and direction of energy transitions, but the world overshoots on emissions and does not achieve the targets to reduce global warming to below 2°C above pre-industrial levels. The transition that unfolds in **Islands** leads to atmospheric CO_2 levels consistent with an average temperature around 2.5°C above pre-industrial levels by 2100, and still rising slowly.

Figure 5: Total final consumption of energy – **Islands** scenario



Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

Figure 6: Total CO_2 emissions – **Islands** scenario



Source: Shell analysis, Global Carbon Project (2020)

In **Islands** ...the world overshoots on emissions and does not achieve the targets to reduce global warming to below 2°C above pre-industrial levels.

SKY 1.5

THE 2020s – *HEALTH* FIRST

In **Sky 1.5**, the initial response to the crises of 2020 is to focus on responding to the pandemic – *health* of humans first, followed by a growing emphasis across the world on the health of the environment. After a slow start, societies across the globe gradually recognise the value of alignment – for example, the successes of collaborative efforts among international medical and scientific communities to develop vaccines are recognised and emulated more broadly.

In fact, initial alignments often arise not through deliberate decisions to collaborate but as a result of common pressures on leaders and nations that result in similar or complementary responses. Resilience is interpreted as reforming and strengthening systems and institutions whose weaknesses have been exposed. Lessons from the effectiveness of green investment in supporting a broader economic recovery lead to significant reforms in energy use and land management practices. Eventually, these reforms enable an increase in negative emissions and put the world on a path consistent with achieving the 1.5°C stretch goal of the Paris Agreement. As systems and institutions are strengthened, and initial alignments provide a platform for more explicit collaboration, the emphasis moves from basic-level structural resilience to transformation of the global energy system.

Managing the virus takes longer than many had initially hoped, and economic reopening is cautious. Paradoxically, this caution eventually results in a steady economic recovery in most countries to pre-pandemic GDP growth rates.

Lessons learned

The early months of the COVID-19 crisis and the lack of international political coordination provide a particularly harsh lesson for governments that contrasts with examples of successful collaboration among medical and scientific communities. A recognition of the value of coordination among domestic agencies, and even internationally, begins to permeate through society.

Under increasing popular pressure, some governments and members of the private sector begin to apply lessons learned to a broader range of societal challenges, including the climate issue. Learning from successful cases during the recovery from the 2008 financial crisis, pioneer leaders in a number of countries respond to the post-pandemic recession with green recovery stimulus packages and more effective alignment.

> "...governments and societies have learned lessons about the value of aligned action, collaboration, social cohesion and robust institutions."

Very significantly, and largely for reasons of domestic industrial and technological competitiveness, the USA, China and other technology-focused economies in Asia and Europe target the development and deployment of cleaner technologies as an economic goal. A race to cleaner technology dominance begins to emerge.

These initiatives provide the impetus for accelerating the structural reshaping of the energy system. OECD countries, which have aligned their policies in relation to pandemic planning, also begin to collaborate to better address the challenge of climate change. And groups of countries with similarly ambitious climate policies quickly band together to use carbon border adjustments to protect competitiveness and prevent carbon leakage. These carbon clubs draw other countries to join them until carbon border adjustments evolve surprisingly quickly into widespread coordinated carbon taxes.

Despite trade disagreements in several areas, the authorities in China and the USA find ways to work together to address pressing global issues that also challenge domestic interests. These include protocols for cybersecurity, the weaponisation of space and response plans for future pandemics. Alignments occur as governments face common pressures – in many cases, initially, without formal agreements on collaboration. In time, however, more nations and organisations participate in agreements at an international level.

Structural reforms and economic development

In the aftermath of the pandemic and economic crises, economies change in many ways. Business travel decreases while working from home increases, especially because young people across the world attempt to lighten their carbon footprints. Renewed social and political attention is directed towards the welfare of those who emerged as key workers during the pandemic and whose circumstances have often previously been precarious and lower income. While the reopening of economies was relatively cautious, governments and societies have learned lessons about the value of aligned action, collaboration, social cohesion and robust institutions. They also turn their attention to necessary improvements in systems whose weaknesses have been highlighted during the pandemic, including public health, education

> ...the mass deployment of cleaner technologies ... accelerate energy transitions and emissions reductions.

and social welfare. These long-horizon structural reforms build the platform for steady economic development over the longer term.

By the late 2020s, three key lessons have become firmly established:

1. governments have relearned that some problems can only be solved through aligned actions and that a key role of government is to stimulate and motivate these actions;
2. businesses have learned better ways to demonstrate commitment to a broader range of stakeholder groups, with a renewed emphasis on social responsibility; and
3. people have recognised that individual choices do matter and are an important contribution to solving large-scale problems.

Global developments in energy demand and supply

The push for a lower-carbon energy system begins with those cleaner technologies that are already approaching full commercial viability. This includes wind and solar power, and the grid infrastructure needed to accommodate them, as well as light-duty battery-electric vehicles. The pace of electrification of the global economy through renewable power accelerates well beyond the historical trend.

From the mid-2020s, the global demand for coal and crude oil begins to decline. Gas is an important substitute fuel for coal in the 2020s, with both Russia and the USA increasing gas exports. As the energy transition accelerates, Russia supports oil and gas production as long as possible, while helping some OPEC countries balance supply with demand in the oil markets. At the same time, Russia also starts to exploit economically other widely available natural resources – namely, nature-based decarbonisation solutions like afforestation and geological formations for carbon capture, utilisation and storage. These same types of natural resources are also available for extensive economic gain in the USA. OPEC countries try to monetise their crude oil and natural gas resources ahead of falling demand, but approach this now by managing supply to maximise revenues rather than maximising the volumes recovered.

> Deeper and more extensive markets are established for the international trading of credits for both greenhouse gas emissions and natural carbon removals such as reforestation...

Following global demand peaks for oil in the 2020s and natural gas in the 2030s, there are rapid declines in demand thereafter. Nevertheless, liquid and gaseous fuels remain essential in the economic sectors that are harder to electrify. The even more rapid natural depletion rates from oil and natural gas-producing reservoirs necessitate investment in production, while the world builds industries for low- and no-carbon fuels.

Crisis as opportunity

By 2030, it has become clearer that the shock of the global pandemic has acted as the necessary catalyst for the messy processes of systemic change. This includes the mass deployment of cleaner technologies that accelerate energy transitions and emissions reductions. A mix of OECD and non-OECD leading countries, including some European nations, China, Japan, South Korea and the USA, have put new policies, regulations and incentives in place to accelerate the development and deployment of these technologies.

By 2030, the mass deployment of these lower-carbon power technologies is already building at a disruptive pace in second-wave countries like Australia and South Africa, spreading rapidly to other countries. Strong competition in the transport sector also brings explosive growth in light-duty electric vehicle manufacturing in China, the EU, Japan and the USA.

Some pioneering governments also incentivise the early deployment of technologies that are not yet commercial at scale, such as fuel cells to make electricity from hydrogen, advanced biofuels for aviation and heavy-freight road transport, and heat pumps and hydrogen electrolysis for residential heating and industrial furnace fuel.

At the same time, leading corporations, financial institutions, cities and other subnational groupings drive sectoral decarbonisation pathways, often by forming coalitions to invest in the development and progressive decarbonisation of the sectors. Capital markets continue to be background driving forces behind many of these alignments, avoiding fossil fuel options perceived to hold long-term risks.

Governments, with strong public support, move in tandem to create the policy frameworks required to subsidise or reward low-carbon approaches and to counter concerns about international competitiveness. Government and private sector alignments are particularly effective where domestic industrial policy considerations, technological expertise, political sentiment and economic strategy come together.

THE IMPORTANCE AND LIMITS OF ENERGY EFFICIENCY

Energy production and use have both become more efficient over time, but the world needs to become even more efficient faster. Nearly all energy outlooks that meet the Paris goal or UN sustainable development goals highlight energy efficiency as the most important contribution.

Efficiency is important partly because it can be improved in so many ways, such as:

- societal and structural efficiency (locating people near work, for example, or working remotely to avoid commuting);
- end-use or energy service efficiency (of cars or steel plants, for example);
- fuel efficiency;
- efficiency gains from energy substitutions (replacing internal combustion engine vehicles with electric vehicles, for example); and
- production efficiency (of power stations and refineries, for example).

Energy intensity (units of energy per unit of GDP) is often treated as energy efficiency even though most of the gains in energy intensity have come from the redistribution of economic activity from heavy industry to services – so while there's a shift in the use of energy, efficiency itself hasn't necessarily improved.

Becoming more efficient faster is not simply a matter of speeding up the current pace. There are counterwinds:

- diminishing returns from technology deployment – for example, a more efficient technology can't have more than 100% of the market share;
- physical limits – for example, efficiency limitations for certain industrial processes;
- practical limits – for example, limits of scale (maximum equipment size), market (marginal business with capital-intensive legacy stock) or logistics (inadequate supply chains); and
- shifts in demand – for example, obtaining metals from ore with declining quality requires more energy.

Increasing energy efficiency is not always the primary objective. Reducing emissions, securing jobs and reducing waste and pollution can have implications for energy efficiency. For example, green hydrogen (produced by electrolysis from renewable energy) could be used to dramatically reduce direct emissions during steel production; however, the process requires more energy input than traditional processes. Circular economy initiatives such as polymer recycling, could reduce demand for new oil; however, more energy is required to break down the old material into usable feedstock. And these are just a few examples.

Despite these obstacles, accelerating investment in energy efficiency, along with global alignment, careful policy design and rapid innovation and technology deployment are keys to building a pathway to Paris.

Pathways to Paris

In addition to greater cooperation and alignment, a third factor that supports the adoption of cleaner technology is public pressure. Climate impacts are becoming more evident, with China and India deeply affected by extreme Himalayan weather. Some heavily populated coastal cities around the world must also deal with rising sea levels and flooding, made worse by more frequent extreme weather events. The consensus of governments around the world is that the Paris mechanisms for international trade in carbon units provide the best available frameworks for working together to drive the necessary changes at the lowest cost. Deeper and more extensive markets are established for international trading of credits for both greenhouse gas emissions and natural carbon removals such as reforestation; and nationally determined contributions are ratcheted upwards. This sends important signals about the future investment climate.

During the 2030s, it becomes apparent to more people that investing in cleaner technologies can offer more opportunities than costs if these costs are appropriately distributed so that specific groups do not feel overburdened or unfairly disadvantaged. And indeed, the costs of commercialising technologies are increasingly recognised as manageable in absolute terms. Costs become recognised as investments. Precise economic predictions being impossible, the guide for making choices in these rapidly changing circumstances becomes minimising potential regrets from missed opportunities. These choices further accelerate progress in decarbonising even the hardest-to-abate sectors like cement and steel.

As the financial as well as environmental benefits of investing in lower-carbon technology become clearer, a strong snowball effect emerges that expands and accelerates crucial changes. Alignments strengthen, a greener shade of politics is deepened by young people who increasingly make environmental concerns a higher priority than earlier generations, and there is explicit attention to addressing the resistance of those who believe they may be negatively affected by change.

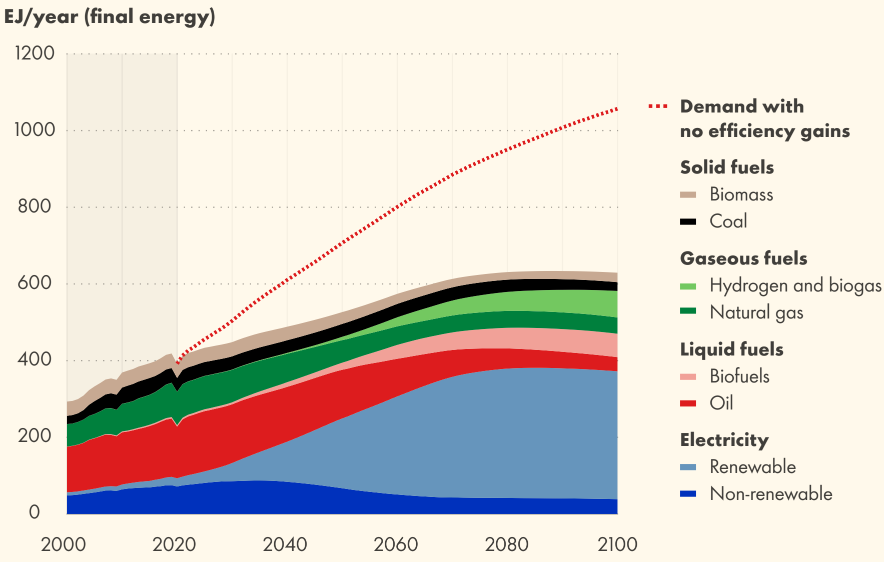
By 2040, modest carbon prices drive out coal and begin to cut the use of gas as fuel for power generation and industrial furnaces, resulting in the retirement of older industrial facilities. The global energy system is characterised by a much deeper electrification of the economy. In addition, hydrogen production, use and infrastructure have become firmly established and there has been rapid growth in the use of advanced biofuels as well as significant advances in the energy and carbon efficiency of economic activity. All these transformations have been strengthened by effective integrated infrastructure, extensive reforestation,[11] deeper and wider carbon pricing and emissions removal through carbon capture, utilisation and storage. Deploying cleaner technologies, smart policies and modest but growing emissions removal have put the world well on the path towards an energy system with net-zero emissions of greenhouse gases by just after mid-century.

Reaching Paris

Societies throughout the world have chosen to engage with the future, to support cultures of learning and experimentation and to build transparent, inclusive, widely supported and accountable systems of cooperation and governance. These choices have been enabled by the emergent alignment of policies and sectors, by government rules and incentives and by pioneer leaders.

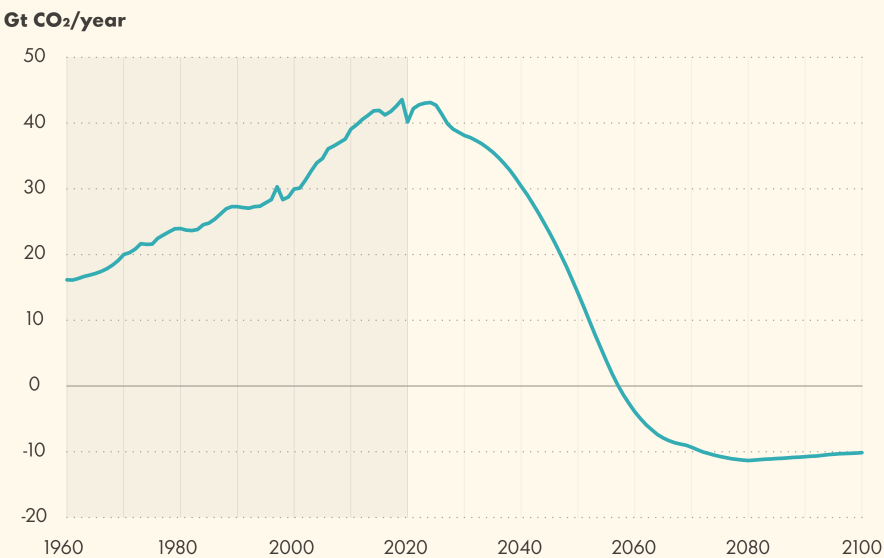
By 2050, in leading economies, the journey that was accelerated by the global pandemic shock reaches net-zero CO_2 emissions.[12] Globally, the world is proceeding towards achieving the stretch Paris ambition – temporarily rising above and then limiting average global warming to 1.5°C above pre-industrial levels before the end of this century (Appendix 1).

Figure 7: Total final consumption of energy – **Sky 1.5** scenario



Source: Shell analysis based on data from the IEA (2020) World Energy Balances (Link), all rights reserved

Figure 8: Total CO_2 emissions – **Sky 1.5** scenario



Source: Shell analysis, Global Carbon Project (2020)

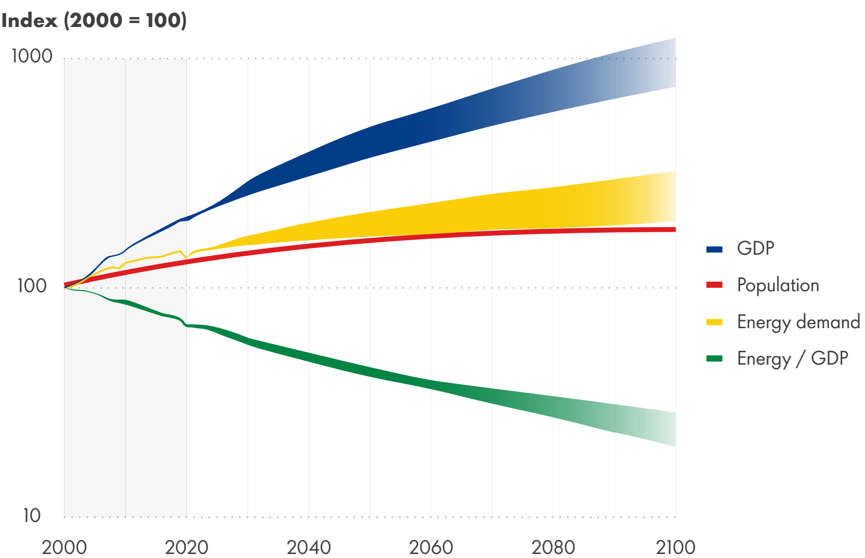
SCENARIO ENERGY LANDSCAPES: A GRAPHIC EXPLORATION

Detailed quantification of the scenario energy landscapes reveals both similarities and differences, that is, both reasonably foreseeable developments and areas of substantial uncertainty or variation.

1 THE WORLD WILL BECOME MUCH MORE ENERGY-EFFICIENT, BUT ENERGY CONSUMPTION WILL STILL GROW

1.1 Structural changes and efficiency improvements will allow the global economy to grow 2-3 times more than energy demand

World trends

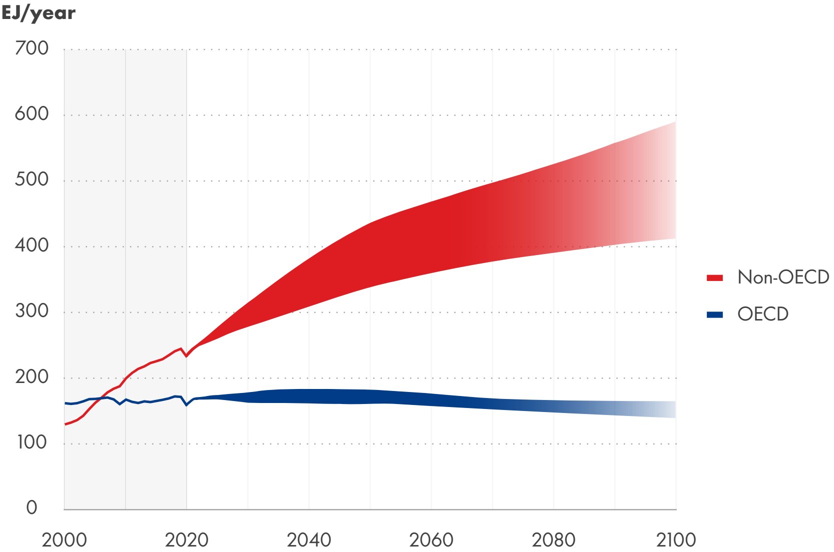


Source: Scenario ranges from Shell analysis based on data from UN Population Division (2019), US Conference Board (GDP) and the IEA (2020) World Energy Balances (**Link**),

Around the world people seek a decent quality of life and the energy to enable this. Improved efficiency and the shifting balance of economies towards service sectors as they evolve, will reduce the average energy intensity of economic activity to as low as a third of today's level. Overall, however, energy demand will increase, mainly because of quality of life improvements in emerging economies and population growth.

1.2 Emerging and developing economies will drive future energy growth, potentially doubling their energy demand by 2100

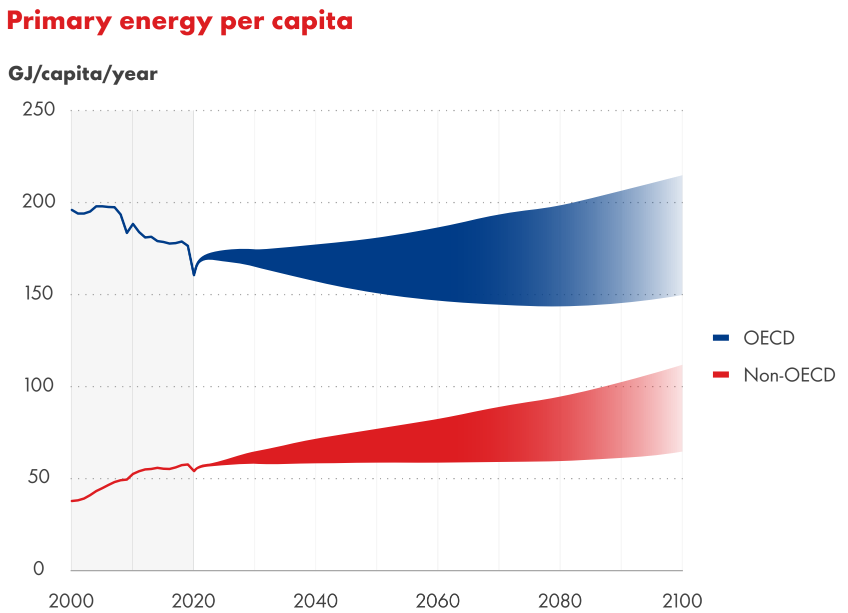
Total final consumption: OECD and non-OECD



Source: Scenario ranges from Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

While developed economies (OECD) have stabilised their energy consumption, emerging and developing economies (non-OECD) still need to grow substantially to provide a decent quality of life for their citizens. These economies will need to pass through the most energy-intensive phases of economic development, including the construction and operation of extensive infrastructure, heavy industries and new urban centres. This will amount to expanding the energy system by the equivalent of two to three times the size of the OECD's current energy system.

1.3 Developing economies need more energy per capita; industrialised economies may need less

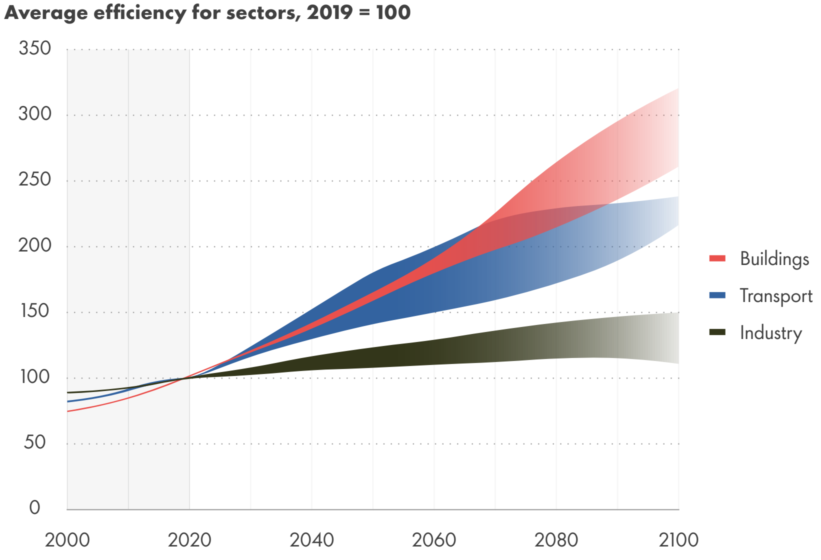


Source: Scenario ranges from Shell analysis based on data from UN Population Division (2019) and the IEA (2020) World Energy Balances (**Link**), all rights reserved

As less developed economies catch up, average energy use per capita in all economies will gradually converge. The energy needs in rapidly growing economies will, however, remain moderate compared to established economies, as more modern and efficient approaches become available to them as they grow.

1.4 Different sectors of the economy have different scopes for efficiency improvement

End-use energy efficiency



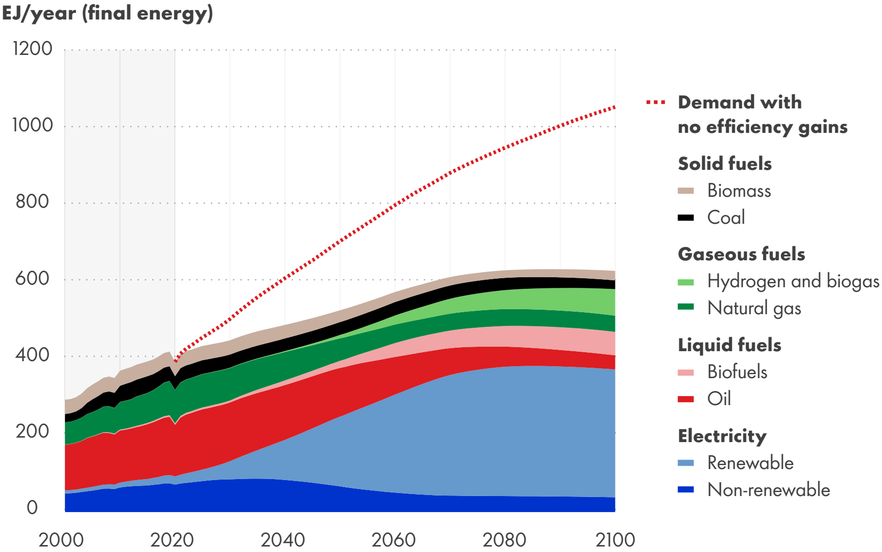
Source: Scenario ranges from Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

Technological advances and, more importantly, the capacity to integrate infrastructure effectively (for example, transport, power, heat, water and waste) will result in substantially greater energy efficiency. The pace of change will differ in different sectors of the economy, given their differences in structure, technology, starting points and rates of equipment and infrastructure replacement. In **Waves** and **Sky 1.5**, efficiency improves much more rapidly than it has in the past.

2 THE ENERGY SYSTEM WILL BE DECARBONISED THROUGH ELECTRIFICATION AND LOW-CARBON FUELS

2.1 Electrification and decarbonisation of fuels will transform the global energy system

Energy use – Sky 1.5 scenario



Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

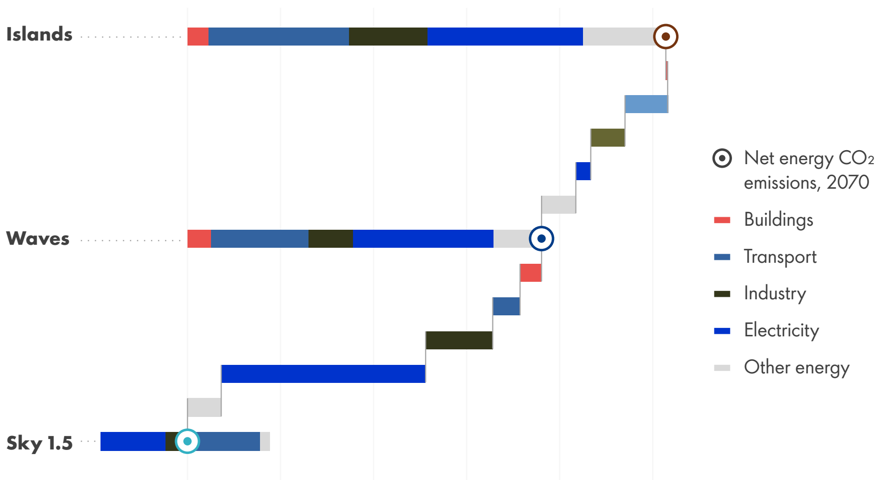
In all scenarios, but most rapidly in **Sky 1.5**, the development and decarbonisation of the global energy system is characterised by:

- accelerated and deep electrification of buildings, transport and industry, with substantial power generation from renewable resources;
- a continued need for energy-dense and portable liquid and gaseous fuels, with progressive deep decarbonisation as biofuels and hydrogen-based carriers penetrate the harder-to-abate sectors; and
- increasing emission removals through carbon capture, utilisation and storage and nature-based processes.

Given technological and policy-driven realities, all scenarios exhibit this general pattern, even though the pace of development differs.

2.2 Growth of electrification through renewables makes the biggest difference to the speed of decarbonisation in the three scenarios

CO_2 emissions from energy

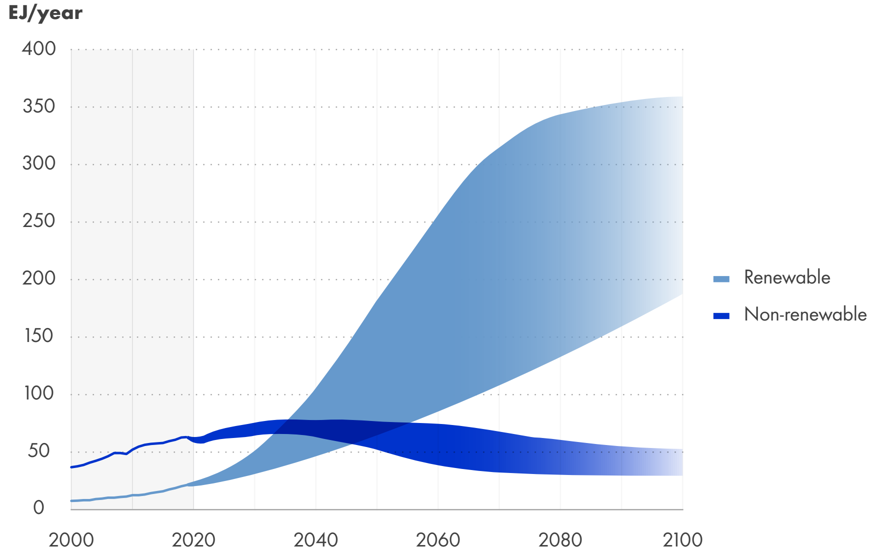


Source: Shell analysis

The energy transition pathways in different sectors of the economy will be quite different because of their inherently different characteristics and end-use technologies. The main difference between scenarios will be the pace of change and not its direction.

2.3 Renewable electricity demand will grow rapidly in all scenarios, increasing power generation by up to four times by 2100

Electricity from renewables and non-renewables

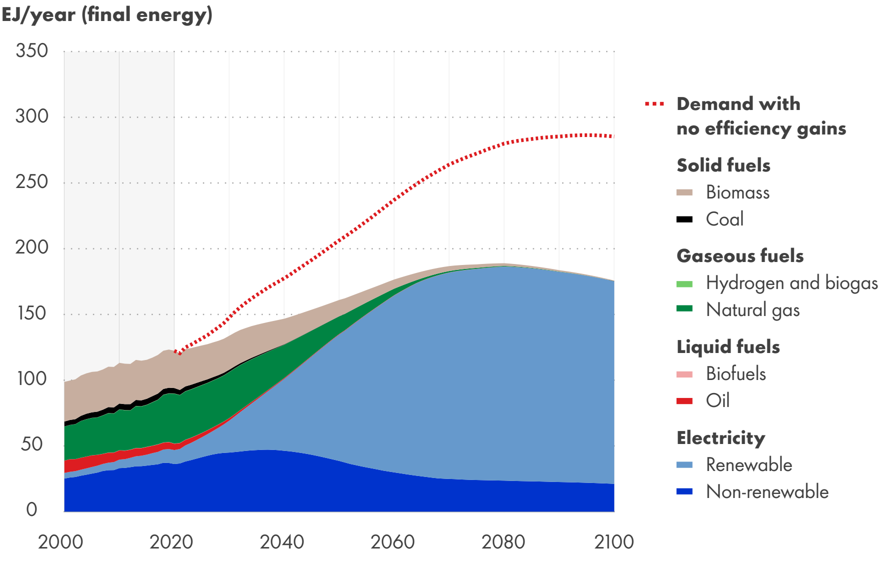


Source: Scenario ranges from Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**),

All three scenarios project a rise in electricity demand of between double and triple current levels. As the highest quality form of energy available to end users, electrification rates tend to rise as economies develop. To date, the rise in electricity demand has been met by increases in both fossil and non-fossil sources, but the future will be dominated by renewables, which need to scale up by as much as tenfold in the next 30 years.

2.4 Buildings are expected to be largely electrified by the 2060s

Energy use in buildings – Sky 1.5 scenario

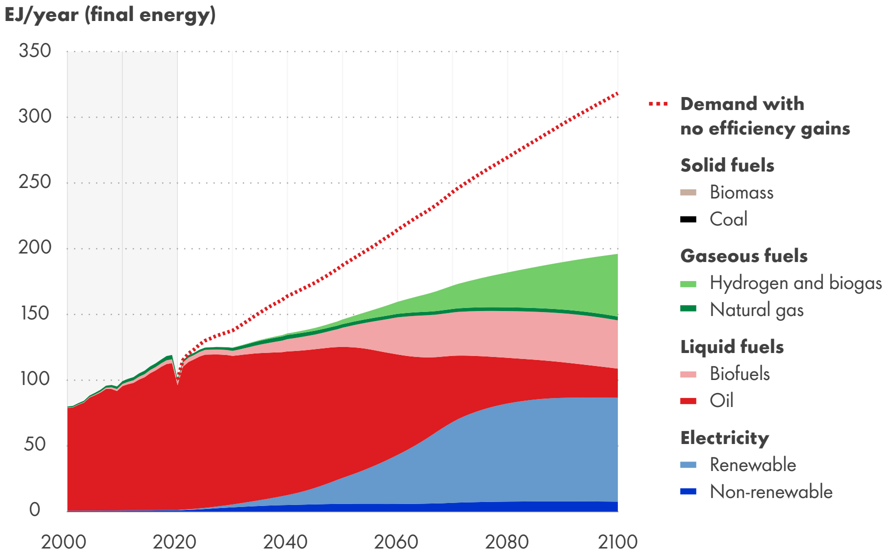


Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

Buildings represent about a quarter of end-use energy consumption, which is currently supplied by a range of sources. Electricity satisfies about 40% of this demand today, but that will be greater than 80% in **Sky 1.5** by 2050 (and 20 to 50 years later in **Waves** and **Islands**). This will be supported by tighter building standards requiring electrification, better insulation to reduce heating and cooling needs, and wider use of modern efficient technologies in lighting, heat and ventilation systems. In developing countries, pursuit of the UN sustainable development goals will lead to a rapid transition from traditional biomass to electricity.

2.5 In transport light-duty vehicles will electrify, but the heavy-freight, aviation and marine sectors will need increasingly decarbonised gaseous and liquid fuels

Energy use in transport – Sky 1.5 scenario

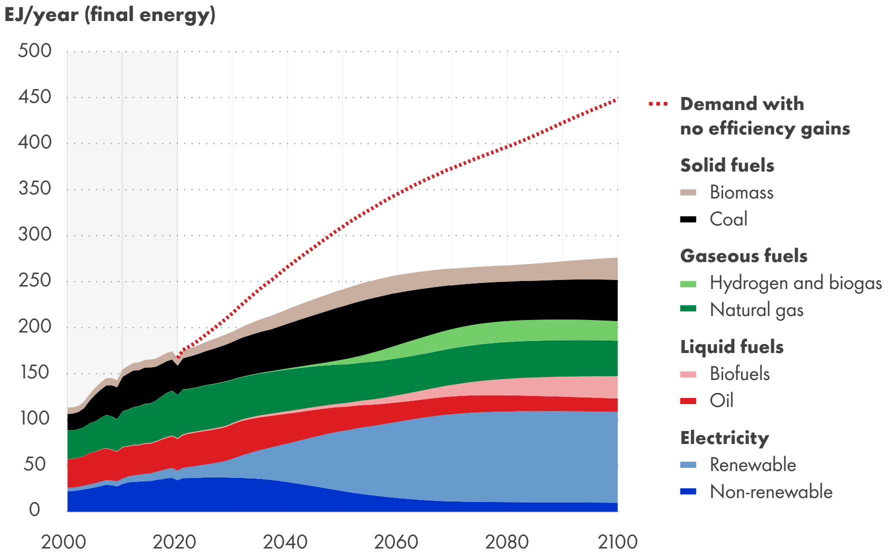


Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

Energy for transport is a similarly significant component of the energy system, requiring portable energy-dense fuels. Oil-based fuels currently dominate the landscape, but the decarbonisation journey will involve electrification of lighter-duty vehicles. In the heavy-freight, marine and aviation sectors, for which batteries will generally be too heavy or too large, decarbonisation will involve significant growth in biofuels and hydrogen or hydrogen-based carriers.

2.6 In industry significant electrification is possible, but molecular fuels and feedstocks will still be needed

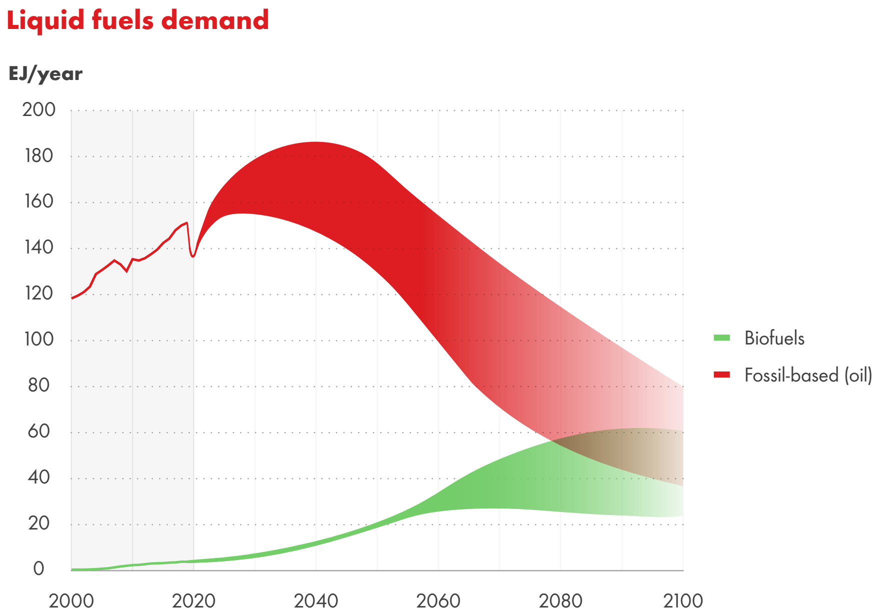
Energy use in industry – Sky 1.5 scenario



Source: Shell analysis based on data from the IEA (2020) World Energy Balances (Link), all rights reserved

Industrial energy consumption is another significant component of global energy demand. Lighter-duty activities, such as low-temperature heating, can be electrified and decarbonised through renewable power. Until there are significant future technological breakthroughs deployed at scale, thermal fuels will still be required for large-scale, high-temperature, heavy-duty furnaces. However, on the decarbonisation journey, coal, oil and gas will be steadily replaced by hydrogen and other non-fossil sources, including biomass. To produce some materials, hydrocarbon feedstocks will still be required.

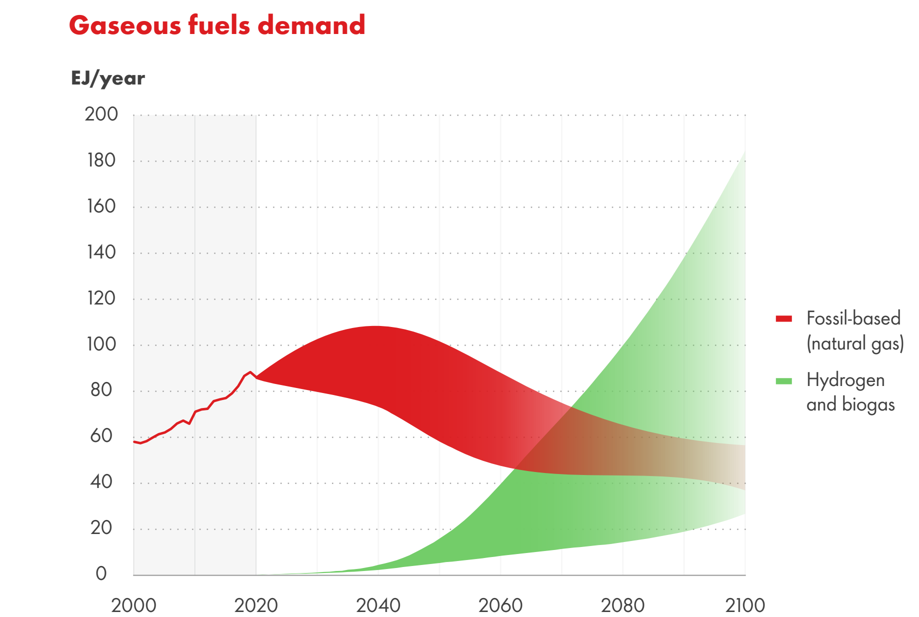
2.7 Consequently, oil demand will peak in the next two decades, then decline as it is replaced by electricity and biofuels



Source: Scenario ranges from Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

The long-term share of liquid fuels (e.g. biofuels and oil-based fuels such as jet fuel and diesel) falls in all three scenarios; however, the prospects in the next 10-20 years are highly differentiated since the mainstay of liquid fuel demand is transport. While transport needs are set to rise significantly as economies grow, the pace of liquid fuel substitution remains uncertain as it depends, for example, on the growth in electric vehicles.

2.8 Gaseous fuels will remain important for longer as they are decarbonised with hydrogen and biomethane

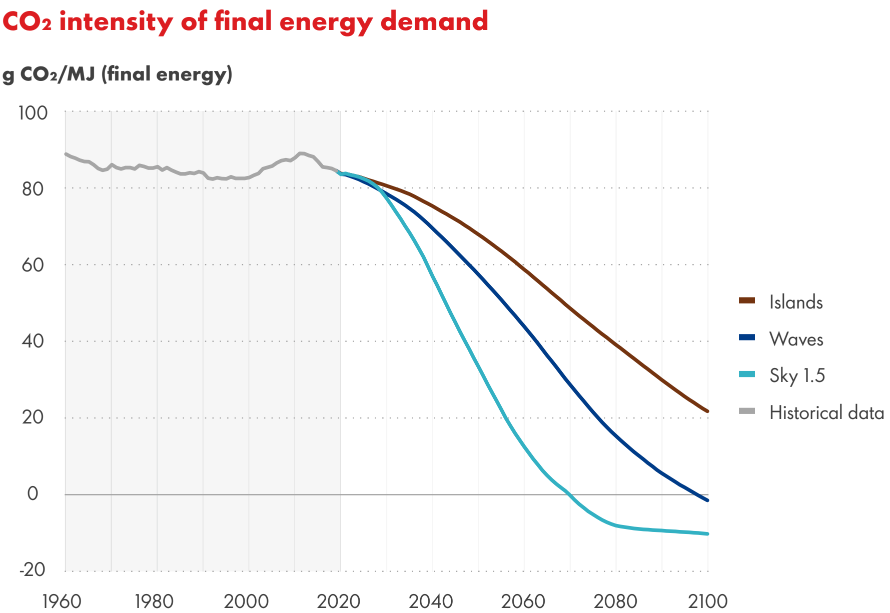


Source: Scenario ranges from Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

Although they require more supporting infrastructure, once installed, gaseous fuels (e.g. biomethane, hydrogen and natural gas) tend to be popular because they are cleaner at point of use, effective and convenient. Biomethane is a simpler substitute for natural gas than hydrogen and could play a valuable role in the mid and long terms. However, realising a large role for gaseous fuels longer term in the energy system will depend on successful, widespread diffusion of hydrogen into the economy.

3 CO_2 EMISSIONS CAN BE BROUGHT UNDER CONTROL – THE ISSUE IS WHEN

3.1 The CO_2 intensity of final energy consumed has been flat for decades, but is about to decline; the question is how steep will that decline be?

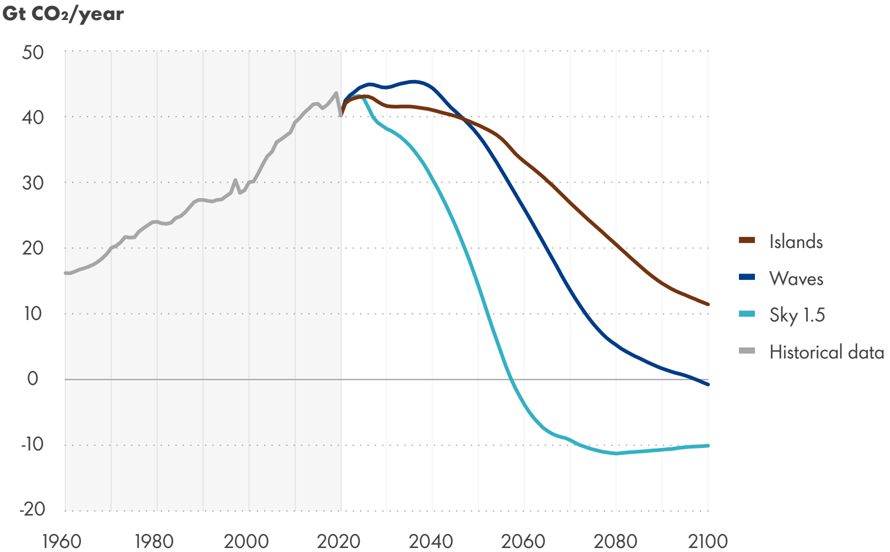


Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**),

Mass deployment of lower-carbon energy technologies is beginning to reduce carbon dioxide intensity, and this will accelerate as energy transitions are driven into the economy by economic attractiveness and policy support.

3.2 In **Sky 1.5** total CO_2 emissions reach net zero by the late-2050s, but in **Waves** and **Islands** net zero is not reached until 2100 or beyond

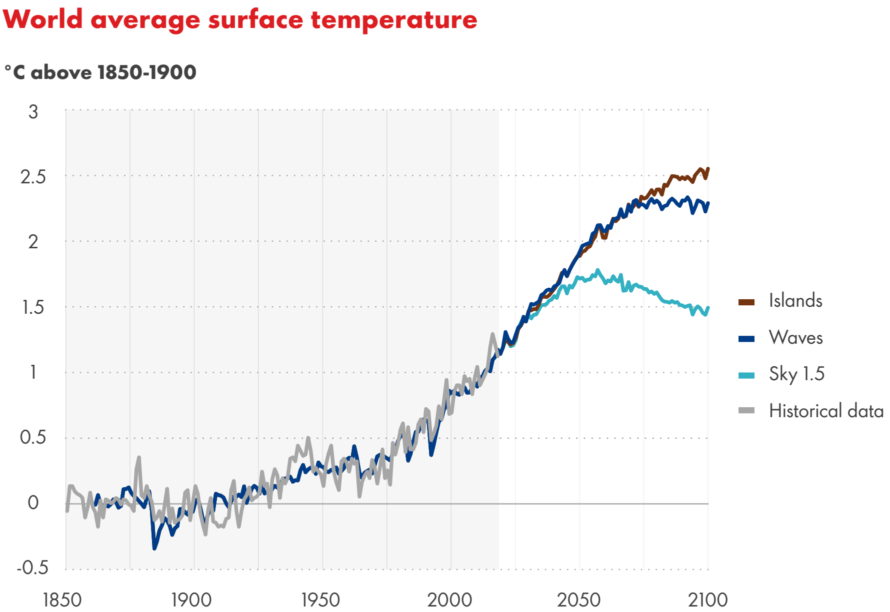
CO_2 emissions



Source: Shell analysis based on data from Global Carbon Project (2020) and the IEA (2020) World Energy Balances (Link),

The most significant energy-related uncertainty that emerges across the landscape of the scenarios is the pace of system decarbonisation. Annual CO_2 emissions have doubled over the last half century. These are starting to plateau and, in **Sky 1.5**, could go into decline by the mid-2020s, reaching net-zero emissions globally by the late 2050s.

3.3 The implications for global warming are significant. Temperature increases can be halted in the 2060s, but could equally continue to rise until the end of the century and beyond



Source: Shell analysis, Met Office Hadley Centre (2020) (temperature history, HadCRUT5), MIT joint program on Global Change (scenarios)

In the **Sky 1.5** scenario, the average global temperature rises above and then is limited to around 1.5°C above pre-industrial levels by the end of the century. In the **Islands** scenario, global warming continues to rise beyond 2100 to more than 2.5°C. People make different choices in the three scenarios – and these choices result in very different outcomes for the environment and quality of life.

3.4 **Sky 1.5** is ambitious, with decarbonisation milestones generally achieved 10-20 years earlier than in the other scenarios

Decarbonisation milestones

	Sky 1.5	Waves	Islands
Peak coal	2014	2031	2028
Peak oil	2025	2037	2037
Peak natural gas	2034	2043	2046
30% electrification of global economy	2035	2046	2066
50% electrification of global economy	2061	2080	>2100
20% of electricity from solar and wind	2029	2031	2035
50% of electricity from solar and wind	2043	2053	2068
20% of passenger vehicle km on electricity	2030	2042	2068
50% of passenger vehicle km on electricity	2046	2059	2086
10% of passenger aviation demand on hydrogen	2082	2057	>2100
20% of passenger aviation demand on hydrogen	2095	2066	>2100
50% CO_2 emissions reduction vs 2019	2046	2064	2078
Net-zero total CO_2 emissions	2058	2098	>>2100

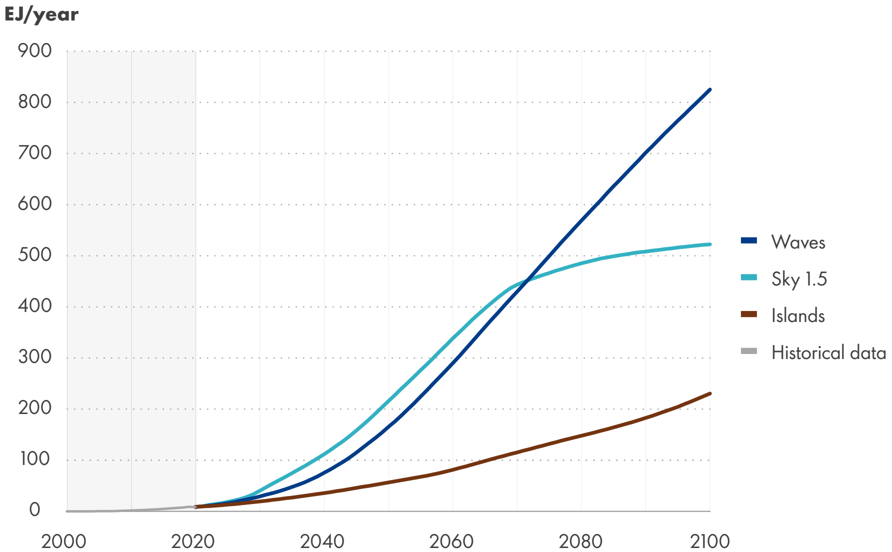
Source: Shell analysis

Different scenarios highlight substantial differences in timing for achieving decarbonisation milestones, many of which hinge on policy choices that encourage customer preferences and provide enough incentive and certainty to underpin the large investments required to support the transition.

4 ACCELERATION OF RENEWABLES, BIOFUELS AND HYDROGEN, AS WELL AS NATURE-BASED AND TECHNOLOGICAL CARBON REMOVAL, ARE NECESSARY TO MEET CLIMATE ASPIRATIONS

4.1 The supply of solar and wind energy varies between scenarios, but is vital to decarbonisation goals

Wind and solar energy supply

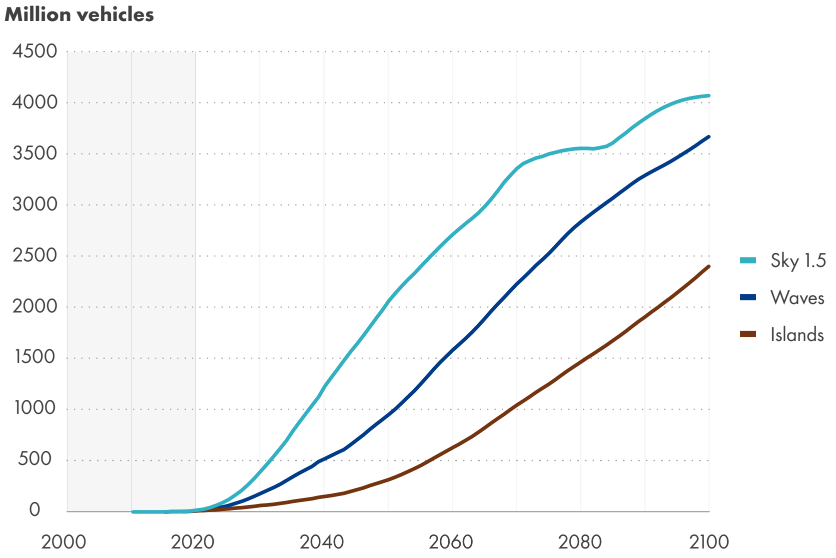


Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

Sectoral differences in emissions between the scenarios highlight particular areas of risk in the decarbonisation journey. The single biggest factor differentiating accelerated emissions reduction in **Sky 1.5** from the other two scenarios is immediate and rapid decarbonisation resulting from rapid growth in the use of electricity across the economy (generated from renewable sources).

4.2 The rise of electric vehicles is vital to decarbonising road transport, but the timing differs significantly across scenarios

Electric vehicle outlook

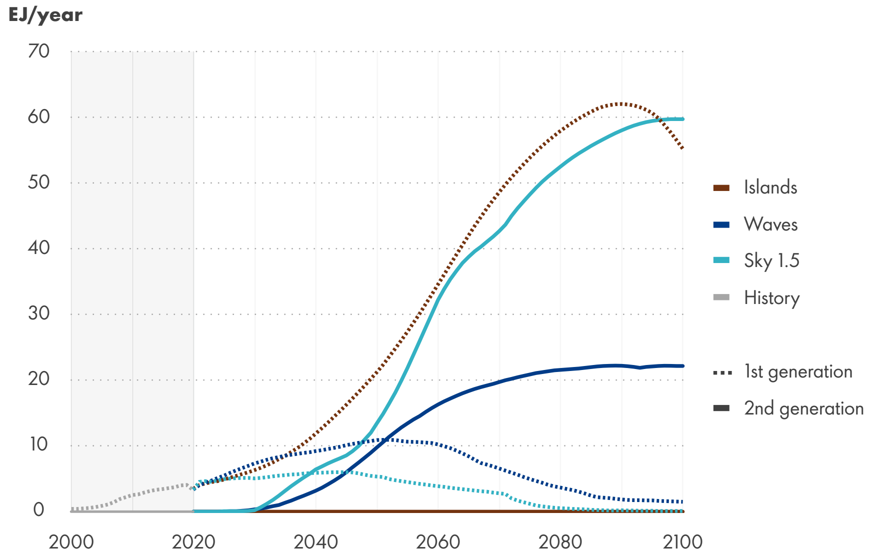


Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**) and Global EV Outlook (**Link**), all rights reserved

Road transport accounts for around half of oil demand today, while electric vehicles (EV) currently make up about 1% of global light-duty vehicles. However, the cost competitiveness of EVs is rapidly improving, supported by government policy in some countries, which could lead to a rapid increase in sales starting this decade.

4.3 Biofuels are required to decarbonise liquid fuels

Biofuels demand

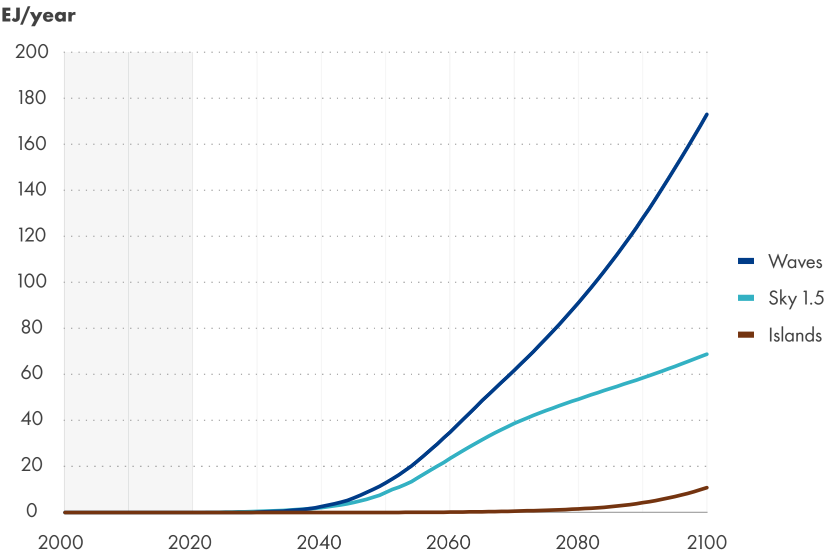


Source: Shell analysis based on data from the IEA (2020) World Energy Balances (**Link**), all rights reserved

The world will still need liquid fuels for a considerable time, particularly in hard-to-abate sectors. For example, between 2019 and 2060, demand for liquid fuels in aviation, shipping and feedstock for chemicals is expected to grow from 15% to 50%. Because of this, growth in biofuels occurs in all scenarios, but with significant ranges of uncertainty depending on both technology breakthroughs and government policy.

4.4 Hydrogen could become a significant energy carrier beyond 2040 depending on policy support, alignment and timing

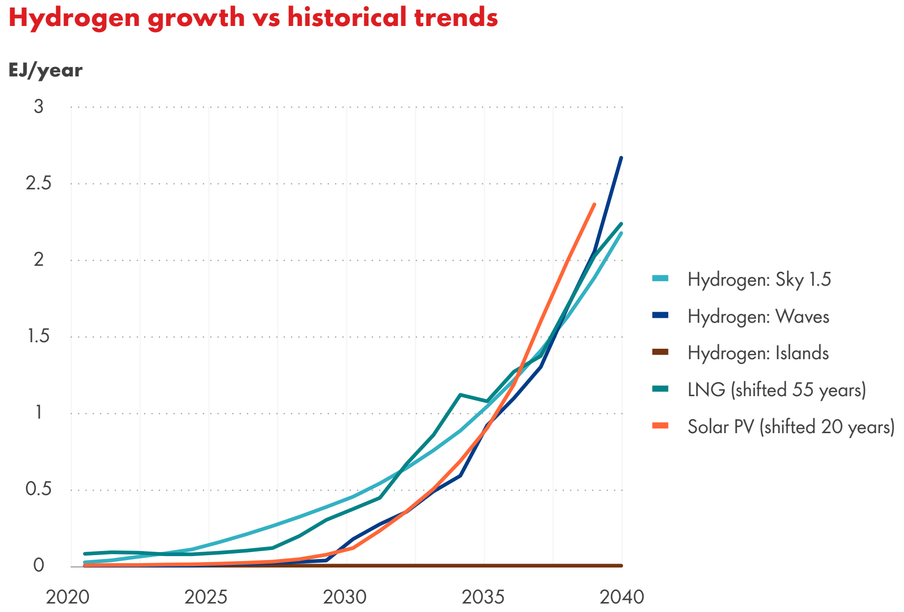
Hydrogen demand



Source: Shell analysis based on data from the IEA (2020) World Energy Balances (Link), all rights reserved

Hydrogen demand growth differs significantly across scenarios in both use and production. Transport and buildings primarily drive early development in **Waves**. Transport drives demand in **Islands**. In **Sky 1.5**, industry and transport drive demand equally. At the same time, hydrogen production could increase, both that associated with natural gas production combined with CO_2 capture and by electrolysis (particularly from renewable power). Currently, almost all hydrogen production is related to natural gas and is used for industrial purposes. Over the longer term, hydrogen production by electrolysis will probably need to grow significantly to achieve net-zero emissions.

4.5 The projected growth of the hydrogen economy may seem dramatic, but it is similar to the historical examples of solar photovoltaic (PV) and liquified natural gas (LNG)

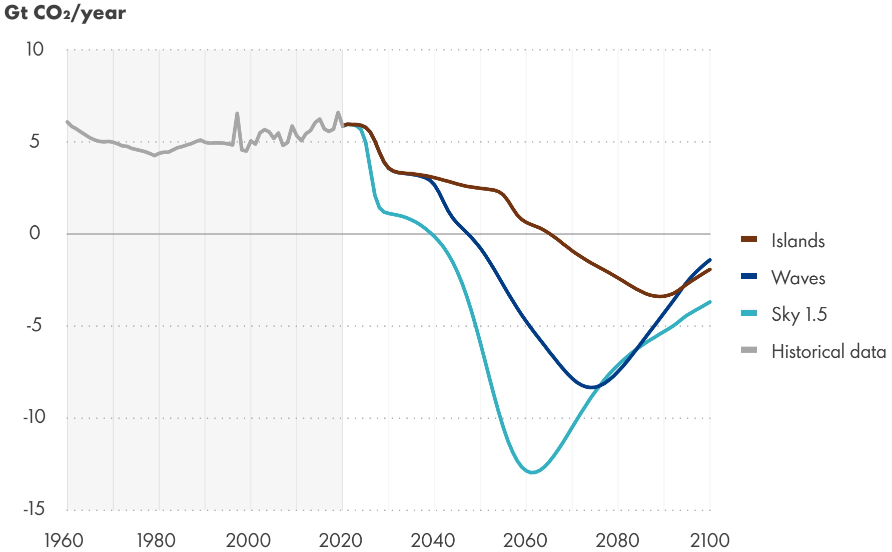


Source: Shell analysis based on data from Rystad Energy and the IEA (2020) World Energy Balances (Link), all rights reserved

Because of its importance in decarbonising hard-to-electrify sectors like heavy transport and industrial furnaces, hydrogen fuel becomes a significant contributor to meeting the stretch goal of the Paris Agreement. The early pace of growth required for this may appear astonishing at first sight, but not when compared with the historical initial growth trajectories of solar PV and LNG. The hydrogen take-off rate in **Sky 1.5** is similar to the LNG take-off rate 55 years earlier.

4.6 Natural capture of CO_2 emissions will be key to meeting the Paris goal, but differs across scenarios

CO_2 removal using nature

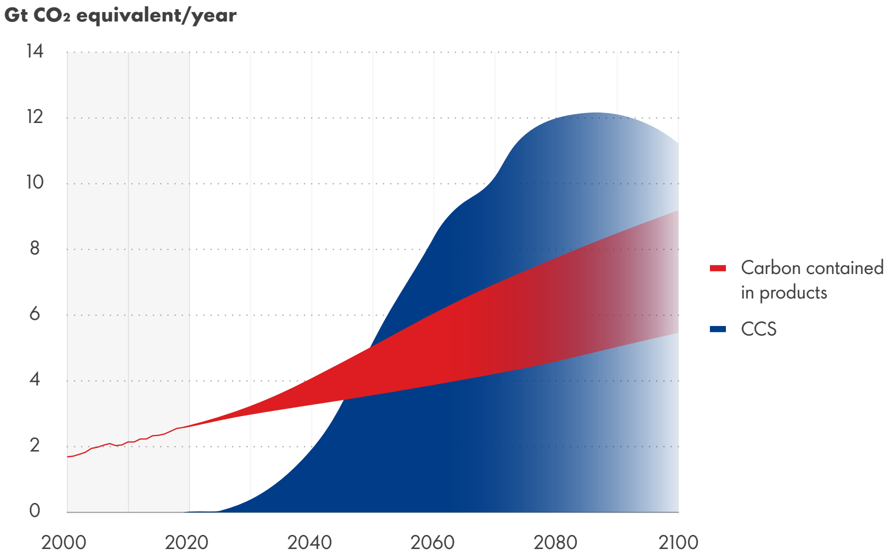


Source: Shell analysis, Global Carbon Project (2020)

The protection and restoration of natural ecosystems can provide many benefits. Nature-based solutions can offer a material contribution to the goal of limiting temperature rise to 1.5°C above pre-industrial levels by bringing the date for achieving net-zero CO_2 emissions earlier by at least a decade. All three scenarios envisage forest restoration, although with different timescales and to different extents. **Sky 1.5** requires major reforestation – some 700 million hectares of land would be required over the century, an area approaching that of Brazil.

4.7 Removing CO_2 emissions with carbon capture and storage (CCS) will be key to meeting the Paris goal; carbon will still be required in product manufacturing, but does not contribute to emissions

CCS emissions removal and carbon in products



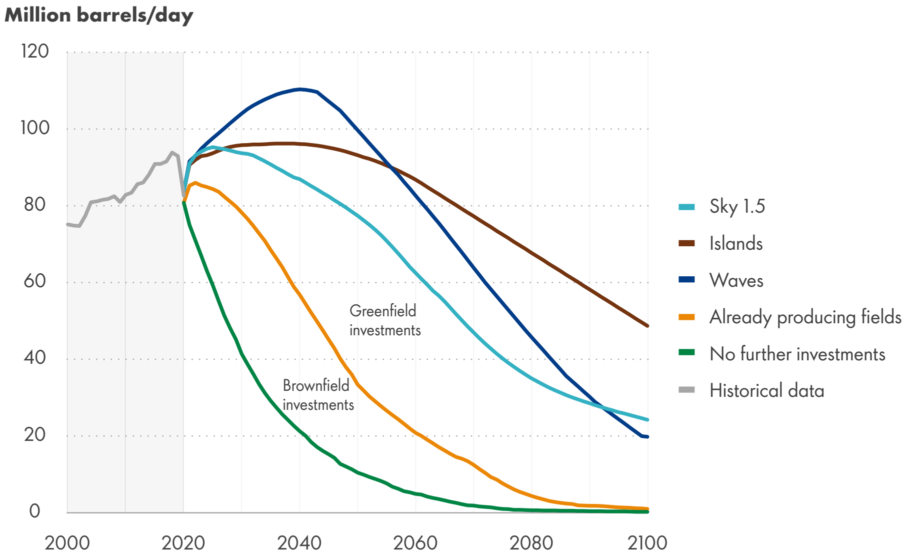
Source: Scenario ranges from Shell analysis

Carbon capture and storage (CCS) plays a significant role in **Sky 1.5** to remove residual emissions, such as, from harder-to-abate sources; this differs between scenarios because of the different policy choices and different levels of attention to decarbonising the harder-to-abate sectors of the economy. In all three scenarios, by late in the century a sizable portion of the remaining carbon from traditional energy sources is used to manufacture products where it is contained and does not contribute to emissions.

5 THERE NEEDS TO BE CONTINUED INVESTMENT IN OIL AND GAS SUPPLY

5.1 The future trajectory of oil consumption differs substantially across the scenarios, but investment continues to be required to offset underlying decline

Total oil* production



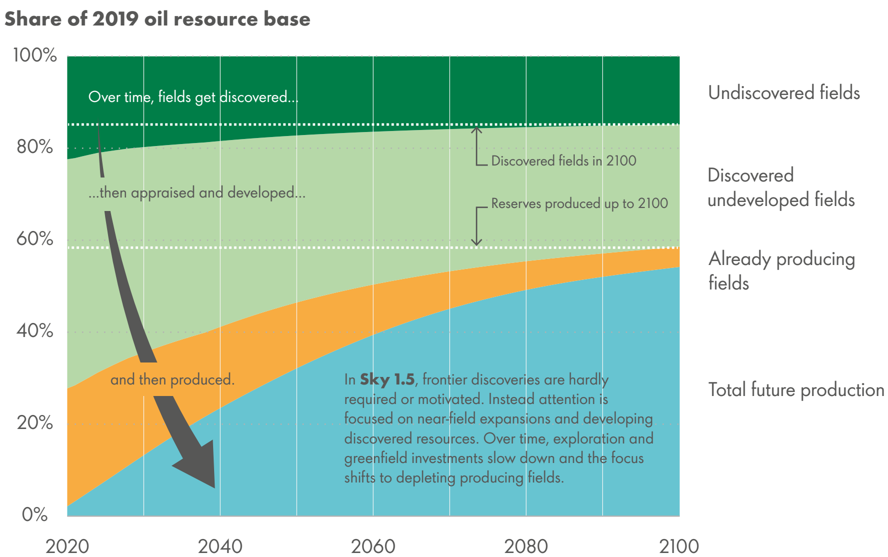
Source: Shell analysis based on data from Rystad Energy

*Oil includes condensate and natural gas liquids

Given the ongoing need for energy-dense liquid fuels, the world will continue to need oil throughout the century. The level of demand, however, will decrease significantly depending on the different paces of energy transition in the different scenarios, particularly in the transport sector. Investments in producing and new oil fields are still required in all scenarios. Fields that are currently producing will not able to meet long-term demand, even in the low-demand **Sky 1.5** scenario.

5.2 Upstream activity will shift from exploring for new oil and gas fields to appraising and developing already discovered fields

Development of new oil* supply – Sky 1.5 scenario



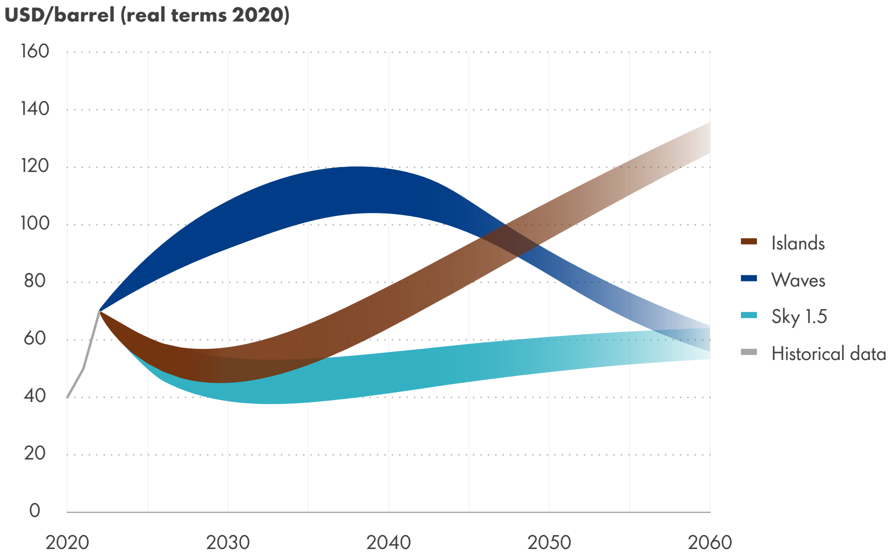
Source: Shell analysis based on data from Rystad Energy

*Oil includes condensate and natural gas liquids

When oil demand growth slows down, exploration for significant new discoveries stops. Producers shift their focus to bringing already discovered fields online and to depleting producing fields.

5.3 The cost of marginal oil supply differs significantly across scenarios

Marginal cost of oil supply

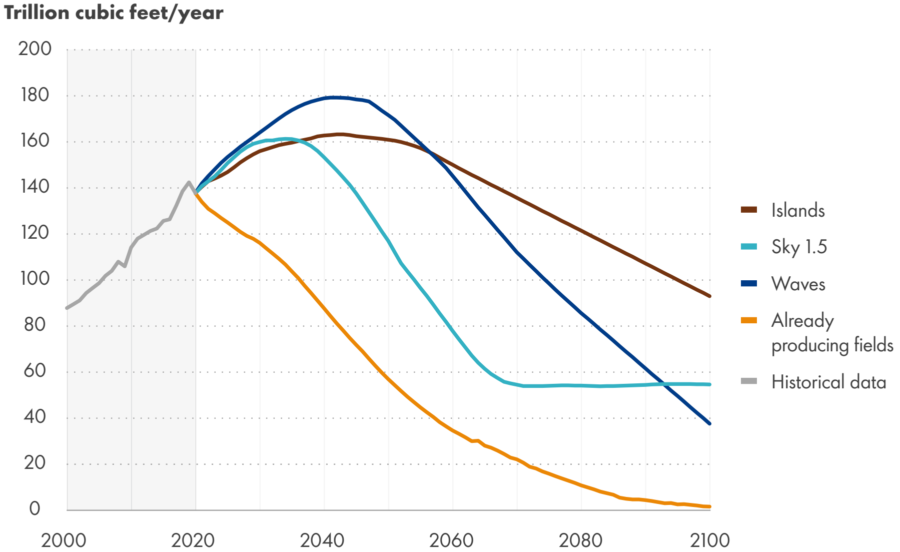


Source: Scenario ranges from Shell analysis based on data from Rystad Energy

The cost of oil supply that must be produced to meet demand varies significantly between the scenarios. In all scenarios, different sources of supply are required to meet higher levels of demand at different times. This brings resources into play with different costs of production. As a result, besides natural short-term volatility as supply and demand come into balance, there is unavoidable longer-term uncertainty about the trajectory of the average future price of oil, as this is partially determined by the cost of marginal supply over the longer term.

5.4 Demand for natural gas is robust in the 2020s, but uncertainties grow after that

Natural gas* production



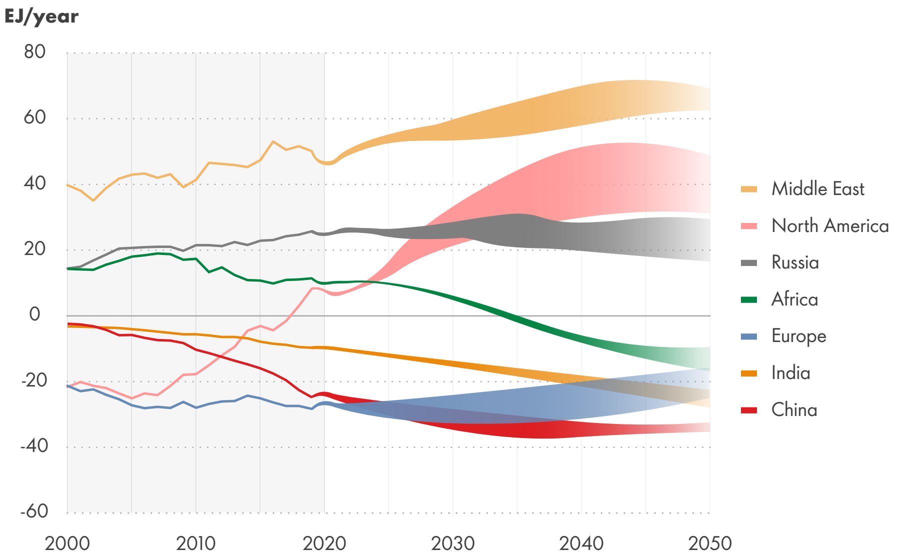
Source: Shell analysis based on data from Rystad Energy

*Natural gas includes associated and non-associated gas

Natural gas is a readily available alternative to coal in power generation and plays an important role in decarbonising the energy system. As a result, investments in gas supply and midstream transport infrastructure initially increase in all three scenarios.

5.5 Exports and imports of oil and natural gas remain substantial features of global energy and will have significant influences on international relations

Oil and natural gas exports and imports



Source: Scenario ranges from Shell analysis based on Rystad Energy data and from the IEA (2020) World Energy Balances (**Link**), all rights reserved

Electrification of economies, enabled by strong growth in domestic renewable power, will shift concerns about energy security. Nevertheless, resources like oil and gas that are very unevenly distributed internationally will remain significant for decades. Substantial global flows of imports and exports will remain a feature of global economic activity.

North America has already shifted from a large historical importer to a small surplus; it is set to become a significant exporter in decades to come. Asia in total only became a net importer of oil and gas as recently as 2018. In all scenarios its imports are set to rise dramatically to 2040, with significant growth in countries like India, even while China's import growth moderates. In totality, Africa will shift from net exporter to net importer. Regional and country oil and natural gas balances will continue to shape geopolitical alignments and rivalries for several decades to come.

> Electrification of economies, enabled by strong growth in domestic renewable power, will shift concerns about energy security.

SECTION THREE

THE ENERGY TRANSFORMATION

Many people see what the world needs to achieve – the vision. And society knows what needs to be done – the pathways. But the world is not yet taking the necessary actions.

THE VISION

The international community is aligned around the UN sustainable development goals (SDGs), which paint a three-part vision for the future of the planet and its people and the role of the energy system.

First, lifting people out of poverty and supporting a better life for all requires more energy services. Nothing can be built, operated or moved without energy.

Second, a better life for all with a healthy planet requires a transition of the energy system from one that relies primarily on fossil fuels to one that uses sustainable sources of energy.

Third, to be achieved at sufficient pace, the transition to a new energy system must be widely supported and, therefore, perceived as fair by the majority of people. Those who believe they will be disadvantaged by the changes must receive appropriate support. With such support, energy transitions can overcome sociopolitical suspicion and resistance. In addition, this could not only broaden energy access and affordability in developing countries, it could also create jobs and improve environmental outcomes in previously underprivileged and underserved communities across the world.

PATHWAYS

The **Sky 1.5** scenario shows what extremely challenging conditions and energy system changes are required to achieve net-zero emissions, including: policy, efficiency, electrification, new decarbonised energy systems and managing CO_2 using technology and nature. There are indeed possible pathways to achieving these goals and reaching net-zero emissions in leading economies by 2050 and globally before 2060 – a timeframe compatible with holding the increase in the global average temperature to 1.5°C above pre-industrial levels before the end of this century.

Simply summarised, the practical requirements for achieving the vision are:

- mass deployment of cleaner technologies;
- changes in behavioural and investment choices; and
- removing emissions that would otherwise accumulate in the atmosphere.

The international community shares a vision and sees possible pathways to achieve that vision. But what could galvanise people to take the necessary steps on those pathways? What can governments, the private sector and society learn from the past that might encourage *action*?

ACTION – OVERCOMING CHALLENGES

One of the most powerful obstacles to action in relation to climate change is that it is happening slowly and largely out of sight – a slow-motion global emergency. Yet, over many decades, there has been growing societal awareness of the climate challenge and the need to transform the way energy is used globally.

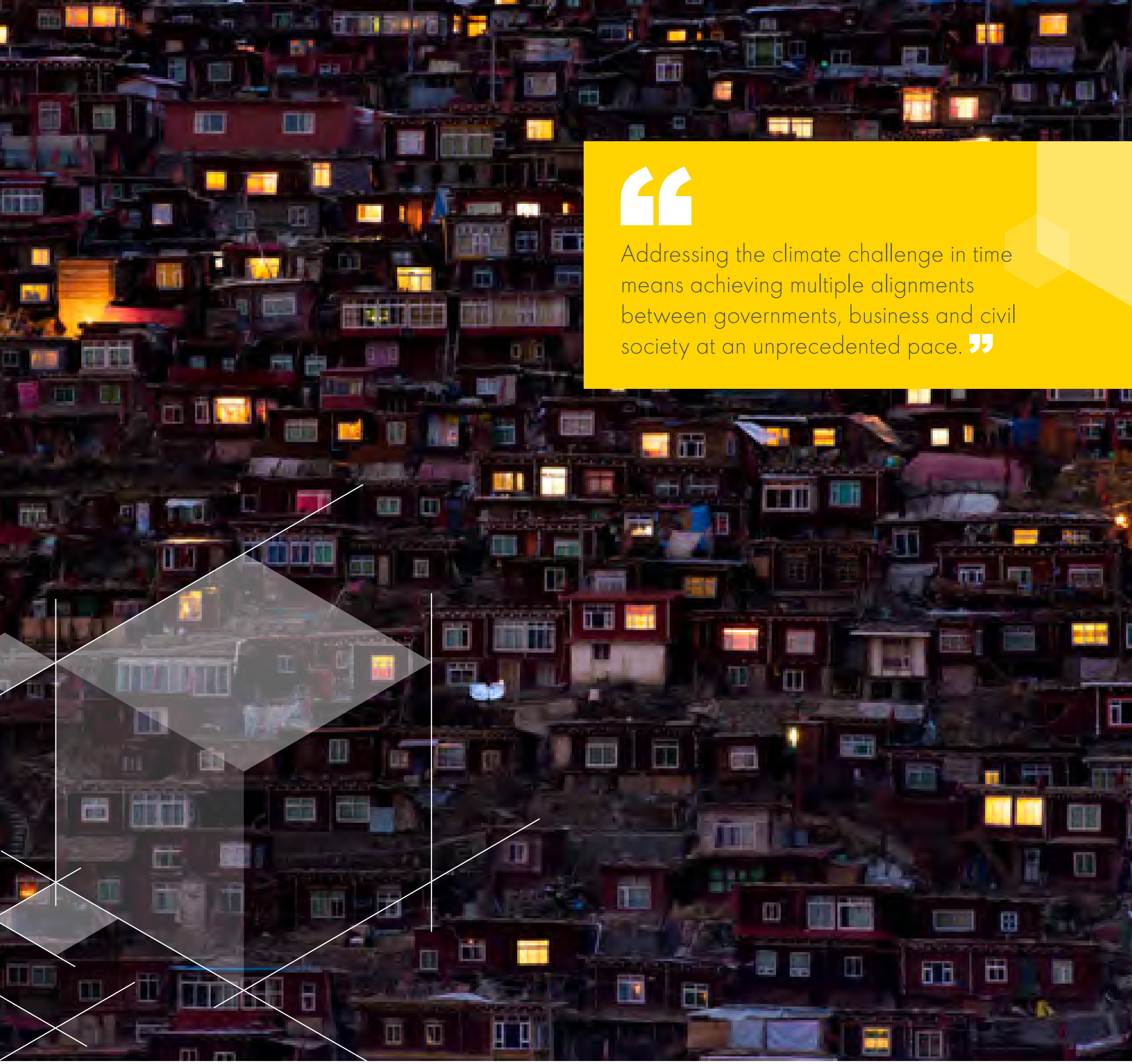
One of the deepest challenges to energy system transition arises from the complexity of that system. There are multiple needs with multiple actors, multiple time horizons for investment and impact and even multiple interests in outcomes. While governments and markets have developed mechanisms to do much of the work in societies to organise complex activities at scale, there simply is not yet the necessary array of markets to achieve new goals. For example, there are no markets yet that reward early deployment of higher-cost cleaner technologies in order drive down future costs. There are no well-established economy-wide global markets that price carbon emissions

A JUST TRANSITION

Actions to ensure a just transition will require additional public spending, whether to support innovation, invest in new mitigation and adaptation infrastructure or manage the effects of the uneven distribution of the transition's costs and benefits. Vulnerable and underserved communities must have access to affordable and reliable energy. They must be resilient to inevitable climate impacts, such as rising sea levels and extreme weather conditions and events. And they must benefit equally from climate mitigation and adaptation opportunities presented by the energy transition.

Successfully managing such societal impacts can be enabled through such measures as reducing the level of energy transition costs falling on low-income households, providing retraining opportunities for workers in carbon-intensive industries, and supporting regions and countries negatively affected by the transition. Temporary support measures may also be needed to shield energy-intensive industries as they transition to low-carbon business models as well as industries exposed to imports of goods from countries that are not on the same rapid transition pathway. Moreover, the energy transition can go even further, delivering better energy, economic and environmental outcomes than the current system through, for example, increased access to cleaner and affordable energy, the creation of jobs, and better environmental outcomes in previously underprivileged and underserved communities across the world.

The European Union's Just Transition Mechanism, part of the Sustainable Europe Investment Plan to finance the Green Deal and the EU's transition to climate neutrality, is intended to mobilise €150 billion between 2021-27 to address the economic and social impacts of the transition to climate neutrality. The mechanism focuses on carbon- and fossil-intensive regions, industries and workers to provide reskilling and new employment opportunities, to invest in more energy efficient housing and reduce energy poverty, and to enable access to cleaner, affordable and secure energy. This is an important contribution to ensuring that the transition to net-zero emissions in the EU is felt to be fair by those who find themselves living through it.



> Addressing the climate challenge in time means achieving multiple alignments between governments, business and civil society at an unprecedented pace.

through trading allowances or that reward reforestation or land-use changes for reducing greenhouse gases in the atmosphere. So, governments need to supplement existing markets with effective mandates and direct incentives alongside the design of new market frameworks.

Addressing the climate challenge in time means achieving multiple alignments between governments, business and civil society at an unprecedented pace. These include alignments leading to technology deployment at scale, the development of new markets, the harmonising of regulations, codes and standards across regions and sectors, the setting of targets, the removal of barriers, research and development support, incentives, transparency and long-term and stable policy frameworks.

THE IMPORTANCE OF SECTORAL DECARBONISATION

The Intergovernmental Panel on Climate Change has made clear that the world needs to undertake rapid and deep transitions in each of the areas that contribute to global emissions: power, transport, buildings, agriculture and industries like steel, chemicals and cement. Decarbonising each of these sectors poses significant and distinct challenges. But even among the most difficult-to-decarbonise sectors, decarbonisation is technically feasible.

In any given sector a handful of pioneer businesses, united by a shared determination to work out how each sector needs to change to be fully in line with the Paris Agreement, can form broad coalitions across the value chain, sector by sector. Then, these businesses, with support from key governments and other parties, can identify and enable viable pathways for each sector to reach net-zero emissions.

Each sector is different, and some are highly fragmented, so the actions needed will vary. An office-based industry like accounting can largely decarbonise by switching to a renewable electricity supply, but solutions are more challenging for sectors like steel or cement. Textiles can move more quickly than chemicals. Passenger vehicles are easier to electrify than heavy-freight vehicles while battery capacity remains a limiting factor.

The transition will involve many changes – from much-needed support for critical technologies, to governments putting into place enabling policies and consumers choosing low-carbon, high-efficiency options.

Progress will involve changes to supply chains and distribution networks, to institutions and infrastructure and to the shape of markets and the rules that govern them. All of this can only happen at the scale and pace the world needs with highly effective coordination.

EXAMPLES OF SPECIFIC SECTORAL ACTION THAT COULD SUPPORT ENERGY TRANSITIONS

Industry

- Project incentives
- Fast-track planning processes

Transport

- City-level action (e.g. low-emission zones)
- Consumer incentives (e.g. EV rebate on purchase)
- Public transport investment

Built environment

- Innovative design competitions
- Efficiency standards and building codes
- Support for retrofitting to meet new standards

> Each sector is different, and some are highly fragmented, so the actions needed will vary.

THE IMPORTANCE OF SECTORAL DECARBONISATION (CONTINUED...)

AN EXAMPLE: STEEL DECARBONISATION WITH HYDROGEN

The steel sector is extremely CO_2 intensive and one of the hardest to abate among industry sectors. Coal is used to produce nearly 95% of virgin steel in blast furnaces – the blast furnace to basic oxygen furnace (BF-BOF) method. The remaining virgin steel is made with a newer direct reduction (DRI) method combined with an electric arc furnace (EAF). DRI is gas-fed, which today means mostly natural gas, although many of the DRI plants in Asia rely on coal-based synthesis gas.

Moving the sector away from coal-fired blast furnace technology to DRI-EAF with hydrogen is currently the only universal route to deep decarbonisation of virgin steel. The critical enabling step is for the sector to widely embrace DRI as its new-build technology and, where reasonable, convert BF-BOF plants to DRI. Whether these new DRI plants start on natural gas or hydrogen matters less in the first instance – the cost to switch from natural gas to hydrogen is minimal.

A large-scale switch to DRI technology will take time and require strong policy support and incentives in most regions. In Europe, such policy support and pressures have already emerged as the result of the net-zero emissions 2050 target, high carbon pricing and ambitious hydrogen strategies. As a result, several global players started moving ahead with hydrogen DRI demonstration projects that should come online in the 2020s. Large-scale commercial deployment of hydrogen DRI technology globally could occur in the 2030s.

With net-zero emission pledges made in 2020 by Japan, China and South Korea, the competition to produce zero-carbon steel using hydrogen DRI technology is also emerging among key national steel producers. Transition to hydrogen DRI in East Asia is critically important, as this region accounts for 75% of global steel production using the BF-BOF method. India is another crucial Asian country for DRI scale-up, as it may likely become the world leader in new-build steel capacity.

The need for alignment underlines a third challenge arising from the current *sociopolitical environment* in much of the world, which appears tilted more towards simplistic divisions than towards complex alignments.

It is only through overcoming these challenges and enabling, for example, the mass deployment of lower- and no-carbon technologies and fuels, like renewable power generation, hydrogen and biofuels, that emissions can be reduced and eventually eliminated. And mass deployment needs competitive and commercial forces to propel it, public policies to support it and behavioural changes on the part of consumers.

30 YEARS AGO, ALL SECTORS LOOKED HARD TO DECARBONISE

Some sectors of the economy, like power generation and personal transport, now look relatively straightforward to decarbonise from a technological point of view, through electricity production from renewables like solar and wind alongside battery-powered electric vehicles that are increasingly affordable and commercially attractive. But 30 years ago, these sectors also looked hard to decarbonise just as now other sectors – like aviation, marine, freight and

INTERNATIONAL COOPERATION AND ARTICLE 6

Article 6 of the Paris Agreement was established to allow cross-border cooperation between countries attempting to fulfil their nationally determined contributions (NDCs). Parties to the agreement are crafting the details of Article 6 to create a foundation for trade in carbon units. The units represent mitigation efforts and the trade opportunity provides a least-cost pathway towards net-zero emissions. Adopting this article has the potential to drive climate action at a faster and larger scale.

A recent study by the University of Maryland, commissioned by the International Emissions Trading Association (IETA), found that a well-functioning Article 6 could deliver savings of $250 billion a year by 2030, which could be reinvested to support additional climate action.[13] However, this outcome depends on the adoption of a clear and transparent set of accounting rules for international emissions trading, as well as on the willingness of individual countries to use tradable carbon units to meet NDC goals.

International trade of carbon units must be designed to prevent such units from being double-counted: once by the country in which the credit is generated and a second time by the entity which buys that credit. Although the negotiation of Article 6 is not final, the primary means emerging to ensure against double counting is for the carbon unit transaction to be accompanied by a corresponding adjustment to the goal of the selling country's NDC.

A fully functioning Article 6 would not only hasten the linking of existing emission trading systems, but it would also encourage developed countries to invest in developing country energy infrastructure and nature-based solutions in exchange for compliance-grade carbon units.

Read more about Article 6 from the World Resources Institute: **Link**.

heavy industry – still look very hard to decarbonise because they require more energy-dense molecular fuels.

Similarly, 30 years ago, there were no government-backed greenhouse gas emissions trading or pricing systems – but today, systems of some nature have been introduced in more than 50 national and subnational jurisdictions. In the USA, for example, a number of cities and states have already instituted green climate policies and the 45Q federal tax credit effectively set a price for capturing and storing CO_2.

From an international perspective, the world has moved from the relative failure in 2009 to build on the Kyoto Protocol via the Copenhagen Accord to the relative success of the Paris Agreement in 2015. Similarly, from a financing perspective, the recommendations of the influential and broadly supported Task Force on Climate-related Financial Disclosures and rapid growth in environmental, social and governance (ESG) investing has highlighted and driven responses to investor concerns.

So there has been progress, even though sometimes slow. How did that progress come about?

> “...aviation, marine, freight and heavy industry, still look very hard to decarbonise because they require more energy-dense molecular fuels.”

LESSONS FROM THE PAST

Times of crisis in the past have been the initial urgent triggers that have directed attention to new areas and incentives for innovation. For example, the oil price crises in the 1970s boosted research on solar photovoltaic production of electricity, battery storage and electric vehicles, most notably in the USA. This research was largely government-funded or subsidised due to concerns about national energy security, although a large part of the work was undertaken in private institutions.

Attention was reinvigorated in the 2000s by a combination of the oil price rise up to 2008 and growing concerns about the environment, climate and energy security. Other factors included improvements in lithium-ion batteries, the global financial crisis (which forced urgent attention on supporting domestic industries and their competitive advantages) and the Fukushima nuclear disaster in Japan.

Private companies stepped up pilot developments in solar power, wind power and passenger electric vehicles, with regulatory support and policy tools that encouraged investment in renewables like the "Energiewende" in Germany, feed-in tariffs in Japan and the mechanisms embodied in California's Global Warming Solutions Act of 2006 in the USA. Companies in China were directed and subsidised to invest heavily in the production of solar panels and batteries, and this activated an additional cycle of competitive and commercial dynamics that boosted deployment of renewable power and battery-electric vehicles elsewhere.

SUPPORTING THE MARKET FOR RENEWABLES

Strong government support for deploying clean technologies at scale has played a vital role in driving commercialisation in areas such as wind power, solar photovoltaic (PV) and electric vehicles. It has also helped deliver strong cost reductions.

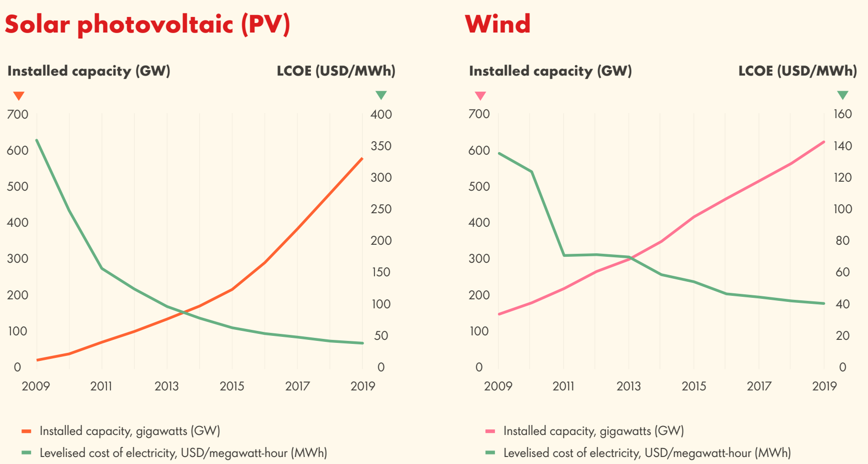
Major manufacturing countries have provided the strongest government support for deploying clean technologies. Japan, India, China, Germany and South Korea are deploying and manufacturing solar PV, and Germany, China and the USA are deploying and manufacturing wind power on a large scale. Together with the EU, these countries account for much of the estimated $2 trillion of investment required to successfully commercialise solar PV and wind power.

In power generation, governments have also increasingly focused on cost-effective measures to support renewables. This includes auctions in which governments issue a call for tenders to install a certain capacity of renewable energy-based electricity. This helped increase solar photovoltaic and wind generation to around 6% of electricity worldwide in 2017, while further accelerating their cost reductions.

Strong government purchase supports of electric vehicles has also created early adopter markets. Electric vehicles account for more than 2% of new vehicles in the largest markets.

The figure below shows that deployment at scale has reduced the costs of solar PV and wind by around 90% and 70% respectively between 2009 and 2018. Similarly, the cost of lithium-ion batteries has decreased by 85% over the same period.

Figure 9: Government price support for electric vehicles is associated with domestic manufacturing activity.



Source: IRENA, Lazard

Source: IRENA, Lazard

In other words, a relatively limited cast of public- and private-sector actors, who were potentially seeking different benefits, found themselves aligned to drive pilot developments forward. These alignments emerged either deliberately or tacitly through concerns about competitiveness and the recognition of potential opportunities. Pioneer leaders and innovative policies and programmes improved the performance of new technologies and drove down their costs dramatically, allowing new players to take them up. Then competitive and commercial considerations kicked in more deeply in response to remaining uncertainties.

More recently, for example, companies like Daimler[14], Volkswagen[15] and General Motors[16] formulated early plans to boost capacity for electric vehicle production this decade. If this proves to be too fast, they would be disappointed with their immediate return on investment; but if they did not invest this way, and the market moved as quickly as it might, they could be out of business entirely. So, they minimised their potential regret by investing ahead of the market – which, of course, in itself has helped accelerate market development.

A resilient recovery from the current pandemic, as vaccines enable a normalisation of many activities, combined with historically low interest rates can support the fiscal capacity of governments to support cleaner technologies. At the same time, low interest rates amid a resilient recovery and increasing risk tolerance by investors can encourage private capital flows and investment towards pioneering cleaner technologies.

Once new technologies become more affordable, then broad-spectrum policy instruments like carbon pricing can finally contribute to spreading developments efficiently across economies. While carbon pricing has generally been insufficient to kick-start the more expensive initial phases of technology innovation and introduction, impact could be profound in later phases of cleaner technology deployment and old technology retirement. For example, in Australia, CO_2 emissions tracked carbon pricing policy development from 2007-13 – declining somewhat when a price was set and rising when the price was removed. More recently, in the UK, as the effective carbon price has risen, coal use has sharply declined. Other policies, such as renewable energy mandates and support, have also played a role.

Macroeconomic costs of transition

The macroeconomic costs globally of achieving climate neutrality are expected to be manageable – estimated to be equivalent to reducing the absolute level of GDP by just a few percentage points in 2050. This figure is dwarfed by other uncertainties in economic development including the potential costs associated with climate change. The impact

> The costs of transition at the macro level, which are manageable, do not hold back progress in energy transitions. It is the distribution of the costs... that can be a barrier.

is perhaps comparable to just one year of economic growth over the period.

For example, according to the Deep Decarbonization Pathways Project[17], the USA can reach net-zero CO_2 emissions at a net cost of 0.4% of GDP by 2050. The government of the Netherlands estimates that the proposed climate accord would reduce GDP by about 1% in 2050, while the UK Committee on Climate Change estimates that a net-zero emissions target will lower the level of UK GDP by only 1-2% in 2050. The impact would also be modest even in emerging economies - by one estimate, the transition to a lower-carbon approach reduces India's GDP only by 4% in 2050 compared to following traditional pathways and with no significant impact on per capita consumption.

The total incremental costs of deploying new technologies and driving them to commerciality offer an historical example. Shell economists estimate that the additional costs for commercialising wind and solar power and light-duty electric vehicles have been $2 trillion over some 20 years, which can be compared with a current global GDP of about $80 trillion a year. This net cost represents just over 1% of the world's capital stock in 2018 – a level of investment not supportable by a single actor, but possible through the tacit alignment of a relatively small number of public and private actors seeking their own different financial, competitive and security objectives.

The costs of transition at the macro level do not hold back progress in energy transitions. It is the distribution of the costs, which varies from place to place and sector to sector, that can be a barrier – for example, shifting from a coal-fired power plant to a solar power facility favours the manufacturers of solar cells and their employees, but reduces demand for the manufacture of coal-fired furnaces and turbines as well as work for coal miners. Many of the costs of commercialising wind and solar photovoltaic were borne by countries that specialise in the manufacture of these cleaner technologies – eventually creating new sources of economic growth, but only after shouldering the burden of change.

Energy transitions may bring positive economic and environmental outcomes in the long term but could be experienced in the short term as a disadvantage or cost for some, and hence may stimulate resistance. This is more of a political economy issue rather than an economic or technological issue, and it is why accelerating sectoral alignments and building widespread societal support for transition is essential. Protecting lower-income groups from uncertainties in the price and provision of energy can remove resistance to transition, with coherent and credible long-term policy frameworks creating policy certainty and keeping transition costs to a minimum. While hugely challenging, if approached well, energy transitions could prove positive for everybody.

Looking back on this history can teach us three crucial lessons for the future:

1. Society-wide shocks can be triggers for driving significant attention to cleaner technology deployment, with sequenced public policy incentives for fundamental innovation, then pilot deployment programmes, then mass-scaling.
2. Emergent alignments, driven by multifold benefits for different actors, are critical to make progress.
3. A core of pioneer governments and companies, with sufficient system awareness and resources to be motivated by broadly conceived self-interests, is crucial to anchor initial alignments.

With the vision in mind, the pathways known and these lessons as a guide: what could society do to accelerate action?

ACTION ACCELERATORS

The world does not have 30 years for the next wave of cleaner technologies to reach the advanced state of readiness of the currently available cleaner energy technologies. However, three powerful accelerators could push the pace of action towards the mass deployment of cleaner technologies beyond the natural or sequential evolution of market forces: alignment, smart policy and pioneer leaders.

1. Alignment – policies, sectors, governments

Transforming the world's energy system means more or less everybody – individuals, companies and governments – making lower-carbon choices. The costs of transition are manageable at the macro level, but a key challenge is aligning the interests of different parties who share differentially in the balance of costs and benefits.

Businesses that supply energy – alongside those in sectors that use energy, such as shipping, buildings, aviation, chemicals, steel and cement – have a significant role to play. The specific actions needed in each sector will vary, but all sectors share the same three ways to make progress:

1. improve energy productivity by making more energy-efficient choices;
2. make changes to enable the use of lower-carbon energy products; and
3. remove or store emissions that cannot be avoided.

The ecosystem around each sector must come together and work out how to take action in each of those three areas to achieve net-zero emissions. In addition, there needs to be greater investment in infrastructure with pervasive common benefits – for example, power systems, networks for hydrogen and other low-carbon fuels and public transport – and better integration, alignment and regulation of this infrastructure.

Alignments occur when different actors respond to common pressures (See *Alignments in shipping: Global Maritime Forum* as an example). There are already signs of such developments. Currently, climate pressures are leading to societal pressures, leading to political pressures, leading to commercial pressures and leading to investor pressures – and thus to emerging alignments.

2. Policy frameworks and incentives

While the individual sectors themselves are best positioned to identify their pathway to net-zero emissions, only governments have the legitimacy, mandate and policy levers to ensure that such pathways are embedded and widely supported. This is often achieved through broader economic encouragement and policies around industrial competitiveness.

ALIGNMENTS IN SHIPPING: GLOBAL MARITIME FORUM

Eighty per cent of world trade is moved on ships, a sector which is a complex, global ecosystem that includes shipbuilders, owners, charterers, operators, cargo owners, ports, fuel suppliers, technology providers, regulators, insurers and banks. The long journeys ships make pose formidable challenges in transitioning to zero-carbon fuels. Given the complexity of the technical challenge and the alignment required across the full supply chain to make progress towards zero-emission shipping, the work of the Global Maritime Forum members in setting up the Getting to Zero Coalition, the Poseidon Principles and the Sea Cargo Charter offers an encouraging case study in what can be done.

The Getting to Zero Coalition started in 2019 with fewer than six businesses. Today it includes more than 120 companies from every part of the shipping ecosystem – all committed to pursuing shipping's "moon-shot ambition" of putting a commercially viable net-zero emissions ship on the water by 2030.

The Poseidon Principles offer a new global framework for assessing and disclosing the climate alignment of ship finance portfolios. The global shipping banks that are signatories to the Principles represent more than a third of the global ship finance portfolio.

Building on the success of the Poseidon Principles, the Sea Cargo Charter of 2020 provides a climate alignment framework for its signatories in the dry and liquid bulk sectors, creating a global baseline and a trajectory by which to measure progress.

These are just three examples of collaborations in the shipping industry. Many more will be needed within shipping and other sectors, including the built environment and heavy industry. These collaborations are necessary for developing fuel production and supply chains, building the necessary new infrastructure, establishing standards for safe operation and supporting the regulatory framework required to decarbonise.

Achieving shipping's moon-shot has the potential to drive green development across the world by encouraging the production of zero-emission fuels – an example of how action in one part of the energy system has the potential to increase momentum for action in other parts of the system.

Getting to Zero Coalition: **Link.**

Poseidon Principles: **Link.**

Sea Cargo Charter: **Link.**

ELEMENTS OF AN EFFECTIVE POLICY FRAMEWORK

Effective policy should include the following broad areas of action:

DRIVE ECONOMY-WIDE CHANGE

1. **Set binding decarbonisation targets and a clear trajectory for achieving them** to reduce policy uncertainty and incentivise necessary investments over time.
2. **Ramp up carbon pricing over time** to improve business and household energy efficiency, incentivise low-carbon choices as they become available and bridge the remaining cost difference to low-carbon fuels and technologies.
3. **Rewire the economy with low-carbon electricity** through investment in low-carbon generation, optimisation of system performance, extensions and expansion of transmission and distribution networks and investment in electrification infrastructure such as electric vehicle charging networks.

ACCELERATE SECTORAL TRANSITIONS

4. **Encourage better coordination within sectoral value chains** for hard-to-electrify sectors in transport (aviation, shipping, heavy road freight) and industry (steel, cement, chemicals).
5. **Provide time-limited fiscal and financial incentives** to drive investment in and commercialisation of low-carbon molecules like hydrogen and advanced biofuels.
6. **Create markets/demand for these low-carbon fuels** through, for instance, sectoral carbon pricing, emissions performance standards and policy mandates.
7. **Support infrastructure planning and investment** to support the commercial adoption of low-carbon fuels.
8. **Establish governance for carbon removals** – both natural carbon sinks and manmade (through carbon capture, utilisation and storage, and bioenergy with carbon capture and storage) – particularly during the transition, to keep the world within its carbon budget and prevent overshoot.

CREATE SOCIETAL SUPPORT

9. **Create clear and predictable policies** that keep overall macroeconomic costs of the transition manageable.
10. **Adopt fair and equitable policies** that mitigate regional, sectoral and distributional impacts of the transition.
11. **Establish transparent and inclusive policies** that encourage wide societal innovation and participation in change.

This points to a need for policies that systematically address barriers to change and any lack of coordination between key players – especially in sectors that are harder to electrify and hence to abate. The right policy frameworks can galvanise multiple domestic interests in cleaner technologies and spur action.

This requires coordination of sector-specific policies, the sequencing of these policies to create markets and generate demand for lower-carbon energy products, and time-limited financial support to make those products commercial and bring them to market.

Policy has a fundamental role in driving the energy transition to net-zero emissions. It can speed up technology development, commercialisation and use, and it can improve the economics of low-carbon goods and services. Policy can also help get the necessary infrastructure built, such as electric vehicle charging networks, and can encourage shifts in consumer mindsets. Achieving climate neutrality will require policy frameworks that are:

- comprehensive and economy-wide;
- coherent within and across sectors; and
- credible and predictable over time.

Long-term policy clarity and legal certainty, both around decarbonisation targets and the processes for monitoring and ensuring progress towards those targets, will help to incentivise the large upfront capital investment needed. But success depends on implementing policies that give appropriate encouragement to pioneer companies.

3. Pioneer leaders

Establishing successful coalitions that reach beyond national borders requires pioneer governments, businesses, cities and civic groups to lead the way and encourage others to join. For example, Apple has committed to become carbon-neutral across its supply chain and products by 2030; Microsoft plans to neutralise all current and historical emissions by 2050; and Unilever aims to achieve net-zero emissions with all its products by 2039.

Developed and developing nations will be expected to have different climate targets and to progress along the pathways to net-zero emissions at different rates – but there can be pioneer leaders among both types of nations. For example, the EU has announced "A European Green Deal" – including European Climate Law committing the EU to becoming climate neutral by 2050. Pioneer developing nations without legacy infrastructure can sometimes leapfrog into more renewable sources of energy, while pioneer developed nations can sponsor the research and development for new biofuels and work on hard-to-mitigate sectors.

CONCLUSION: CRISIS AS AN OPPORTUNITY

A deadly pandemic, deeply disrupted economies globally and climate change – the need for transformative resilience has never been greater. This current crisis offers the opportunity to arouse the sense of urgency the world needs to catalyse action across a broad front.

Global societies may make choices that push the world more in the direction of the **Waves**, **Islands** or **Sky 1.5** scenarios, and each of these will have attractive features for some people. However, because almost everyone will benefit from reducing the impacts and risks of increasing global climate change, the type of developments described in **Sky 1.5** are likely to be in the interests of most people. Global societies may need to be prepared for any of the scenarios with a focus on their own resilience, but no one can be a passive spectator. Everyone makes choices, and can encourage, cooperate and compete with others to make broader ranges of aligned choices. Global society can pursue transformative resilience more broadly and influence which type of pathway the world will face.

The required pace of change is extremely challenging, but technically and economically feasible if action accelerates decisively from now. And, as history has shown, sometimes shocks galvanise people into action.

“Global societies may need to be prepared for any of the scenarios with a focus on their own resilience, but no one can be a passive spectator.”

APPENDIX 1

A WORD ON CARBON BUDGETS

In the Intergovernmental Panel on Climate Change Special Report on 1.5°C (IPCC SR15), one table stood out and has been widely used and cited. Specifically, Table 2.2 (see extract below) addresses the issue of the remaining carbon budget and its uncertainties.

The table notes that for the 50th percentile point of the distribution of the transient climate response to cumulative emissions for 1.5°C, the remaining carbon budget from 1/1/2018 is 580 gigatonnes (Gt) of CO_2. This means that if cumulative CO_2 emissions exceed 580 Gt from 1/1/2018, it is as likely as not that warming relative to 1850-1900 will exceed 1.5°C.

Approximate warming since 1850-1900, °C	Remaining carbon budget (excluding additional Earth system feedbacks) [Gt CO_2 from 1/1/2018]. Percentiles of transient climate response to cumulative emissions of carbon		
	33rd	50th	67th
~1.5°C	840	580	420
~2.0°C	2030	1500	1170

The numbers that the IPCC presented in 2018 emerge from the coming together of numerous climate scientists representing many different academic and research institutions, drawing on multiple independent modelling assessments of the carbon budget question. These assessments present a distribution of outcomes across institutions, models and scenarios, within which the average numbers in Table 2.2 sit.

IPCC SR15 presents four archetype mitigation pathways (representative of some 100 different model runs) that meet the stretch 1.5°C temperature goal of the Paris Agreement. All four exceed the remaining carbon budget for 1.5°C based on gross emissions to the atmosphere and depend on some level of atmospheric carbon dioxide removal (CDR) to balance against the budget, either through natural removal (e.g. forests), industrial removal (bioenergy with carbon capture and storage) or both. Due to the relative phasing of emissions and removals, two of the scenarios exceed 1.5°C before returning to below 1.5°C by 2100. These are referred to as overshoot scenarios, and **Sky 1.5** is such a story. The other two scenarios peak at 1.5°C and end the century below 1.5°C. In the case of **Sky 1.5**, data for the years 2018, 2019 and 2020 have effectively reduced the remaining carbon budget further. This information was not available for IPCC SR15, which was released in 2018. Emissions from the start of 2018 to the start of 2021 have already reduced the IPCC budget by some 120 Gt, leaving just 460 Gt. This represents less than 12 years of emissions at current levels.

While an approximate assessment of warming resulting from a given pathway can be made using linear interpolation or extrapolation of a given carbon budget against the cumulative CO_2 emissions of that pathway, that is not the approach taken in our scenario analysis. Rather, we rely on an assessment of warming from a fully integrated climate model that looks at all greenhouse gases and accounts for shifting physical phenomena, such as ocean uptake of heat and feedback from the land-based system. Shell does not operate such a model, but instead we partner with the MIT Joint Program on the Science and Policy of Global Change, making use of their extensive modelling capability. Our modelling relationship with the Joint Program extends back to 2006, when they assessed our *Blueprints* and *Scramble* scenarios.

The Joint Program analysis of the **Sky 1.5** scenario implies a carbon budget that is higher than the 580 Gt number presented by the IPCC, yet still results in warming of 1.5°C in 2100, albeit with overshoot to around 1.7°C in the middle of the century. The cumulative CO_2 emissions for **Sky 1.5**, from 1/1/2018, peak at 1,149 Gt in 2057 (as CO_2 emissions reach net zero in 2058) before cumulative emissions from 2018 fall to 747 Gt in 2100, and hence the implied central estimate (median) carbon budget for 1.5°C is 747 Gt CO_2. A wide range of estimates for the remaining carbon budget has been reported.[18] This result is within the uncertainty range of the estimates reported in the literature.

APPENDIX 2: QUANTIFICATION

Please visit The Energy Transformation Scenarios online for additional data tables and further information on the scenarios quantification.

Summary outlook: **Waves**

Total final energy consumption by sector

	EJ / year														
	1980	1990	2000	2010	2019	2020	2025	2030	2040	2050	2060	2070	2080	2090	2100
Heavy industry	36	37	43	62	70	66	73	76	84	91	96	101	111	122	131
Light industry	51	56	44	60	65	60	68	72	82	85	84	84	85	86	90
Services	17	19	23	30	34	24	38	44	55	65	70	74	75	74	72
Transport - ship	6	6	8	11	12	11	12	13	14	15	15	14	14	14	13
Transport - rail	3	2	2	2	2	2	3	3	3	3	4	4	4	4	4
Transport - road	36	47	60	76	91	82	106	122	143	156	163	166	173	184	196
Transport - air	6	8	9	11	14	8	14	16	18	22	26	31	34	37	41
Residential	53	64	76	83	89	96	95	102	114	123	122	118	113	106	99
Non energy use	15	20	25	32	39	40	43	46	52	59	66	74	84	96	109
Total	**224**	**260**	**292**	**367**	**417**	**389**	**452**	**494**	**566**	**619**	**645**	**667**	**693**	**723**	**756**

Totals may not sum due to rounding.

Total primary energy by source

	EJ / year														
	1980	1990	2000	2010	2019	2020	2025	2030	2040	2050	2060	2070	2080	2090	2100
Oil	131	136	154	174	192	171	202	216	228	209	169	124	92	67	46
Natural gas	51	70	87	115	140	135	150	161	175	169	143	111	80	62	48
Coal	76	94	97	153	159	150	166	169	161	145	122	89	53	28	14
Nuclear	8	22	28	30	30	28	35	38	48	61	77	106	129	142	149
Hydroelectricity	6	8	9	12	15	15	18	20	26	29	29	30	30	30	30
Biofuels	0	0	0	3	4	3	5	8	12	21	27	26	25	24	24
Biomass and waste	10	12	14	19	26	25	30	32	37	43	49	59	71	88	115
Biomass - traditional	21	26	29	29	27	26	26	27	27	24	18	13	9	6	4
Geothermal	0	1	2	2	4	3	5	8	20	34	62	91	99	103	104
Solar	0	0	0	1	4	4	7	14	40	97	187	300	424	545	660
Wind	0	0	0	1	5	5	9	16	36	68	103	129	145	156	165
Other renewables	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total	**303**	**369**	**421**	**540**	**607**	**567**	**652**	**709**	**811**	**901**	**987**	**1,080**	**1,158**	**1,253**	**1,361**

Totals may not sum due to rounding.

Summary outlook: **Islands**

Total final energy consumption by sector

	EJ / year														
	1980	1990	2000	2010	2019	2020	2025	2030	2040	2050	2060	2070	2080	2090	2100
Heavy industry	36	37	43	62	70	66	72	74	79	84	88	93	96	98	101
Light industry	51	56	44	60	65	61	66	69	73	76	77	76	76	76	75
Services	17	19	23	30	34	24	35	37	41	44	44	44	45	47	48
Transport - ship	6	6	8	11	12	11	12	12	13	13	13	13	13	13	13
Transport - rail	3	2	2	2	2	2	3	3	3	3	4	4	5	5	5
Transport - road	36	47	60	76	91	82	96	101	108	114	120	124	124	121	114
Transport - air	6	8	9	11	14	8	14	15	16	18	19	22	24	27	29
Residential	53	64	76	83	89	96	89	92	95	97	95	91	88	87	88
Non energy use	15	20	25	32	39	40	42	45	49	53	58	63	68	73	79
Total	224	260	292	367	417	389	430	448	477	502	518	530	538	546	552

Totals may not sum due to rounding.

Total primary energy by source

	EJ / year														
	1980	1990	2000	2010	2019	2020	2025	2030	2040	2050	2060	2070	2080	2090	2100
Oil	131	136	154	174	192	172	194	198	199	192	179	161	142	121	98
Natural gas	51	70	87	115	140	136	144	152	161	160	148	134	120	105	91
Coal	76	94	97	153	159	151	159	160	154	144	129	108	88	69	54
Nuclear	8	22	28	30	30	28	31	31	25	21	31	43	55	82	120
Hydroelectricity	6	8	9	12	15	15	16	16	18	19	19	18	20	21	23
Biofuels	0	0	0	3	4	3	5	6	12	21	35	49	58	62	55
Biomass and waste	10	12	14	19	26	26	29	32	39	49	59	68	78	90	99
Biomass - traditional	21	26	29	29	27	26	25	26	27	27	24	19	15	13	11
Geothermal	0	1	2	2	4	3	4	5	8	12	17	23	28	32	39
Solar	0	0	0	1	4	4	6	10	23	40	63	95	124	153	189
Wind	0	0	0	1	5	5	7	10	13	16	18	21	24	30	42
Other renewables	0	0	0	0	0	0	0	0	0	0	0	2	2	3	3
Total	303	369	421	540	607	568	622	647	678	704	723	740	755	781	823

Totals may not sum due to rounding.

APPENDIX 2: QUANTIFICATION CONTINUED...

Summary outlook: **Sky 1.5**

Total final energy consumption by sector

	EJ / year														
	1980	1990	2000	2010	2019	2020	2025	2030	2040	2050	2060	2070	2080	2090	2100
Heavy industry	36	37	43	62	70	66	72	75	82	87	87	82	77	75	73
Light industry	51	56	44	60	65	61	69	73	79	82	86	88	87	85	84
Services	17	19	23	30	34	26	38	44	57	72	86	95	99	97	94
Transport - ship	6	6	8	11	12	11	12	13	15	16	16	16	16	16	15
Transport - rail	3	2	2	2	2	2	2	2	3	3	3	3	3	3	3
Transport - road	36	47	60	76	91	80	95	94	99	103	110	117	123	127	130
Transport - air	6	8	9	11	14	8	15	15	19	25	30	35	40	44	48
Residential	53	64	76	83	89	96	89	90	90	89	91	91	90	86	82
Non energy use	15	20	25	32	39	40	43	47	59	72	84	94	104	112	119
Total	**224**	**260**	**292**	**367**	**417**	**390**	**435**	**454**	**502**	**549**	**593**	**623**	**639**	**646**	**648**

Totals may not sum due to rounding.

Total primary energy by source

	EJ / year														
	1980	1990	2000	2010	2019	2020	2025	2030	2040	2050	2060	2070	2080	2090	2100
Oil	131	136	154	174	192	172	197	194	180	160	129	97	72	59	50
Natural gas	51	70	87	115	140	135	148	157	151	115	77	54	53	54	54
Coal	76	94	97	153	159	151	161	155	130	100	73	56	50	51	52
Nuclear	8	22	28	30	30	29	34	42	64	80	97	112	120	123	124
Hydroelectricity	6	8	9	12	15	15	16	16	18	19	21	23	23	23	23
Biofuels	0	0	0	3	4	4	5	5	12	19	36	46	54	59	61
Biomass and waste	10	12	14	19	26	26	30	34	54	81	97	104	126	124	122
Biomass - traditional	21	26	29	29	27	26	25	24	17	9	4	2	1	0	0
Geothermal	0	1	2	2	4	3	3	4	12	28	37	38	39	38	39
Solar	0	0	0	1	4	4	10	25	70	127	218	313	353	379	399
Wind	0	0	0	1	5	5	9	15	42	88	120	130	133	129	123
Other renewables	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Total	**303**	**369**	**421**	**540**	**607**	**570**	**638**	**673**	**750**	**828**	**910**	**975**	**1,024**	**1,040**	**1,049**

Totals may not sum due to rounding.

ACKNOWLEDGMENTS

We wish to thank the many people consulted externally in the development of The Energy Transformation Scenarios.

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We also wish to thank The Nature Conservancy.

The scenario analysis in this publication is partially based on historical data from the International Energy Agency's (IEA) World Extended Energy Balances©, OECD/IEA 2020. The work has been prepared by Shell International B.V. and does not necessarily reflect the views of the IEA. We also wish to acknowledge Rystad Energy, whose upstream data cube is an important input for our oil and natural gas supply modelling.

ENDNOTES

1. Shell scenarios, including these scenarios, are not the Shell strategy or business plan. When developing Shell's strategy, our scenarios are one variable among many that we consider. Ultimately, whether society meets its goals to decarbonise is not within Shell's control.

2. Future energy: In search of a scenario reflecting current and future pressures and trends, MIT, Nov 2020: **Link.**

3. A Better Life with a Healthy Planet, Shell, 2016: **Link.**

4. **Sky** scenario, Shell, 2018: **Link.**

5. The **Sky 1.5** scenario starts with data from Shell's **Sky** scenario, but there are important updates. First, the outlook uses the most recent modelling for the impact and recovery from COVID-19 consistent with a **Sky 1.5** scenario narrative. Second, it blends this projection into existing **Sky** (2018) energy system data by around 2030. Third, the extensive scale-up of nature-based solutions is brought into the core scenario, which benefits from extensive new modelling of that scale-up. (In 2018, nature-based solutions required to achieve 1.5°C above pre-industrial levels by the end of this century were analysed as a sensitivity to **Sky**. This analysis was also reviewed and included in the IPCC Special Report on Global Warming of 1.5°C (SR15).) Fourth, our new oil and natural gas supply modelling, with an outlook consistent with the **Sky 1.5** narrative and demand, is presented for the first time. Fifth, the **Sky 1.5** scenario draws on the latest historical data and estimates up to 2020 from various sources, particularly the extensive International Energy Agency energy statistics. As with **Sky**, this scenario evolves from exploratory to normative; this means that it is rooted in stretching but realistic development dynamics today, but also explores a goal-oriented way to achieve the ambitions of the Paris Agreement to be well below 2°C above pre-industrial levels. **Sky 1.5** achieves the 1.5°C stretch goal. We worked back in designing how this could occur, starting from the realities of the situation today and taking into account realistic timescales for change. Of course, there is a range of possible paths in detail that society could take to achieve this goal. Although achieving the goal of the Paris Agreement and the future depicted in **Sky 1.5** while maintaining a growing global economy will be extremely challenging, today it is still a technically possible path. However, we believe the window for success is closing quickly.

6. Turbulence: A corporate perspective on collaborating for resilience, Roland Kupers (editor), Amsterdam University Press, May 2014.

7. Digital minilaterals are the future of international cooperation, Filer and Weiss, Brookings, October 2020: **Link.**

8. Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study, Prof Stein Emil Vollset, DrPH, et al, The Lancet, October 2020: **Link.**

9. Based on production of around 15 million barrels per day (bpd) by major international oil companies (BP, Chevron, ExxonMobil, Royal Dutch Shell and Total) on a total of close to 100 million bpd.

10. IEA, World Energy Investment 2020: **Link.**

11. Nature-based solutions have an estimated maximum potential to extract around 600 Gt CO_2 from the atmosphere, storing it sustainably in land-based ecosystems, for example in improved soils and extended forest cover. Natural climate solutions, PNAS, Griscom et al, 2017: **Link.**

12. The Shell Scenarios team has outlined possible pathways for the EU and USA to transition to lower-carbon energy systems by 2050:
A Climate Neutral EU by 2050: **Link.**
and A US Net-Zero CO_2 Energy System by 2050: **Link.**

13. The Economic Potential of Article 6 of the Paris Agreement and Implementation Challenges, Edmonds, et al., IETA, September 2019: **Link.**

14. Ambition 2039: Our path to CO_2-neutrality, Daimler: **Link.**

15. Even more boost for the Volkswagen electric offensive: World car ID.4 now on the way to the world markets, Volkswagen, February 2021: **Link.**

16. General Motors, the Largest U.S. Automaker, Plans to be Carbon Neutral by 2040, General Motors January 2021: **Link.**

17. Deep Decarbonization Pathways Project (DDPP) is a global consortium formed in October 2013 which researches methods to limit the rise of global temperature due to global warming to 2°C or less: **Link.**

18. Estimating and tracking the remaining carbon budget for stringent climate targets, Rogelj et. al. Nature, July 2019.

GLOSSARY

Advanced biofuels	Liquid biofuels produced from non-food crops, including forest products. Also called cellulosic biofuels or second-generation biofuels.
California's Global Warming Solutions Act	The California Global Warming Solutions Act of 2006, also referred to as Assembly Bill 32 (AB32), requires California to reduce its greenhouse gas emissions to 1990 levels by 2020 – a reduction of about 15% below emissions expected under a business as usual scenario.
Carbon border adjustments	A tariff or tax imposed on goods imported into a country where the carbon emission costs for domestic producers of the same or similar goods exceed those in the country where the goods originated.
Carbon budget	A certain rise in global average surface temperature is approximately linked to the cumulative amount of anthropogenic CO_2 released into the atmosphere. To limit warming to a given amount, there must therefore be a limit on the cumulative carbon dioxide release prior to the point of net-zero emissions when no further CO_2 is released into the atmosphere. This limit is the carbon budget.
Carbon clubs	Groups of nations that coordinate their climate policies along lines of similar ambition to align their carbon pricing regimes and foster links between carbon trading systems.
Carbon leakage	Refers to the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints. This could undermine national competitiveness and lead to no change in overall emissions, despite the imposition of a carbon emissions cost in a particular country.

Energiewende	The ongoing transition by Germany to a low-carbon, environmentally sound, reliable and affordable energy supply.
Feed-in tariffs	A feed-in tariff is a policy tool designed to promote investment in renewable energy sources. This usually means promising small-scale producers of energy – such as solar or wind energy – an above-market price for what they deliver to the grid.
Nationally determined contributions	The actions countries take to reduce greenhouse gas emissions under the Paris Agreement.
Net-negative emissions	The Paris Agreement calls for a "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of the century." This emphasis on a balance – or what is also referred to as net-zero emissions – is a critical development because it recognises that surface temperature warming is directly related to the cumulative total of CO_2 emitted into the atmosphere. If total cumulative emissions overshoot a threshold, it may be necessary to go beyond net-zero emissions to achieve net-negative emissions, where more CO_2 is extracted from the atmosphere than continues to be released.
Net-zero emissions	According to the Paris Agreement, net-zero emissions is a "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of the century." As the level of CO_2 in the atmosphere rises, so does the surface temperature of the planet. Globally, if net-zero emissions are reached early in the second half of this century, warming should plateau well below 2°C above pre-industrial levels. For this reason, many policymakers in advanced economies are aiming to achieve net-zero emissions by 2050.

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Shell's scenarios are not intended to be projections or forecasts of the future. Shell's scenarios, including the scenarios contained in this report, are not Shell's strategy or business plan. When developing Shell's strategy, our scenarios are one of many variables that we consider. Ultimately, whether society meets its goals to decarbonise is not within Shell's control. While we intend to travel this journey in step with society, only governments can create the framework for success. The **Sky 1.5** scenario starts with data from Shell's ***Sky*** scenario, but there are important updates. First, the outlook uses the most recent modelling for the impact and recovery from COVID-19 consistent with a **Sky 1.5** scenario narrative. Second, it blends this projection into existing ***Sky*** (2018) energy system data by around 2030. Third, the extensive scale-up of nature-based solutions is brought into the core scenario, which benefits from extensive new modelling of that scale-up. (In 2018, nature-based solutions required to achieve 1.5°C above pre-industrial levels by the end of this century were analysed as a sensitivity to ***Sky***. This analysis was also reviewed and included in the IPCC Special Report on Global Warming of 1.5°C (SR15).) Fourth, our new oil and natural gas supply modelling, with an outlook consistent with the **Sky 1.5** narrative and demand, is presented for the first time. Fifth, the **Sky 1.5** scenario draws on the latest historical data and estimates to 2020 from various sources, particularly the extensive International Energy Agency energy statistics. As with **Sky**, this scenario assumes that society achieves the 1.5°C stretch goal of the Paris Agreement. It is rooted in stretching but realistic development dynamics today, but explores a goal-oriented way to achieve that ambition. We worked back in designing how this could occur, considering the realities of the situation today and taking into account realistic timescales for change. Of course, there is a range of possible paths in detail that society could take to achieve this goal. Although achieving the goal of the Paris Agreement and the future depicted in **Sky 1.5** while maintaining a growing global economy will be extremely challenging, today it is still a technically possible path. However, we believe the window for success is quickly closing.

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