Shell Scenarios

A CLIMATE-NEUTRAL EU BY 2050

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In the 50 years since its creation, the Shell Scenarios team has sought to make a constructive contribution to public debate on a wide range of issues – including energy transitions and climate change.

We have developed this sketch for a climate-neutral EU in response to the European Union’s (EU) efforts to tackle climate change. It illustrates a technically and economically possible but still highly challenging pathway to achieving Europe’s climate ambitions.

Travelling that pathway means building widespread support for the necessary changes in the economies of countries within the EU. This means emphasising direct local benefits for jobs, industrial competitiveness, health and the environment. Cross-sector collaboration, for example in aviation and shipping, will also be essential – with pioneers needed in government, business and civil society.

There is much that Shell can do as a business. But there are also limits to what society can achieve without the policy frameworks needed to align, guide and motivate all those on the journey. We applaud the steps being taken to develop the policy agenda through the European Commission’s Green Deal and believe this can complement other steps to recover from the impact of the 2020 pandemic. Realising a climate-neutral EU will not be easy, but we believe that, with widespread support and better alignment of interests, these targets could indeed be achieved.
INTRODUCTION

In December 2019, the European Commission announced “A European Green Deal” – including the European Climate Law committing the EU to becoming “climate neutral” by 2050. The Green Deal sets out a way to align EU policies around the 2050 target, taking a comprehensive system-wide approach and fundamentally resetting the EU’s energy and climate policies. Importantly, it also sets out a strategy for stimulating economic growth and industrial competitiveness, and for supporting an inclusive and “just” transition.

There are still several outstanding questions that need to be answered. What, for example, must change for the EU to achieve climate neutrality by mid-century? What could a European energy system consistent with climate neutrality look like? How does society get there? And which policies are needed to support that change?

As an energy business that aims to contribute to the global effort to tackle climate change and help support the goals of the Paris Agreement – and committed to serving the needs of customers across Europe – Shell is determined to explore these areas.

In 2018, Shell published a detailed scenario called Sky, which explored a challenging but technically possible pathway for society to achieve net-zero emissions from global energy by early in the second half of the century. This included an outline of the energy transformation and land use changes needed to potentially limit the rise in global average temperature to 1.5°C above pre-industrial levels, the stretch goal of the Paris Agreement.

Energy-related CO₂ emissions fell by 5% in Europe in 2019 – even as the economy grew and as energy transition policies and technologies progressed. In the context of the adoption of the European Green Deal, the Shell Scenarios team has taken a deeper look at the developing situation in the EU, reflecting on lessons learned from our Sky scenario, emerging insights and ongoing developments around the world. This scenario sketch is an overview of that assessment.

The European Green Deal is, on the one hand, our vision for a ‘climate-neutral’ continent by 2050, on the other hand, a very dedicated roadmap to this goal... We do not have all the answers yet. Today is the start of the journey. But this is Europe’s man-on-the-moon moment. ”

Ursula von der Leyen
President of the European Commission, December 11, 2019
LENSES ON ENERGY TRANSITIONS

The world must move faster to achieve the goals of the Paris ambition.

Building on our Sky scenario, we have taken a fresh look at the situation: reflecting on emerging insights, historical progress and ongoing developments in the world. The purpose is to explore the practical steps needed to accelerate the collaboration and collective action necessary to achieve the goals of the 2015 Paris Agreement.

During the next months, we are looking more deeply at countries, regions and sectors to explore potential net-zero emission pathways that can contribute to the stretch goal of a 1.5°C world.

Jeremy Bentham

KEY INSIGHTS

- It remains technically possible for society to achieve the stretch goal of the Paris Agreement.
- The required pace of change is highly challenging. Society is not currently on course to achieve climate neutrality by 2050.
- The cost to society of the transition is expected to be manageable, although aligning the interests of all parties is challenging.
- Different countries and sectors will move at different speeds, but all need to move as fast as possible.
What needs to happen

Action already happening must speed up and additional actions must be taken to reduce emissions more quickly. Decisions made today on infrastructure, and how it is interconnected, will have far-reaching consequences for the power sector, public transport and the emergence of lower and zero-carbon gases, such as hydrogen and biomethane. Action taken must;

- accelerate mass deployment of clean technologies and energies;
- target behavioural incentives through policy and markets. Infrastructure choices and the availability of low-carbon substitutes play an enabling role; and
- remove unavoidable emissions through carbon capture, utilisation and storage (CCUS), bioenergy with carbon capture and storage (BECCS) and natural carbon sinks like reforestation.

How to make progress

- A just transition - fair for all. There will be wins and losses as society moves towards its lower-carbon future. Great effort must be made to ensure a just transition in order to secure full support from society.
- Sectoral coalitions for action. Governments and businesses must pursue net-zero emission pathways on a sector-by-sector basis. Initially, this action will need to be launched by pioneer governments and businesses.
- Coherent and credible policy frameworks. These need to be predictable and consistent over time. Smart policies should include incentivising early-stage clean technology deployment and an ever-stronger role for carbon pricing mechanisms. These should also be complemented by regulations such as sector-specific mandates to create demand for and accelerate investment in cleaner energy.

Actions to get moving today

1. Plan deep electrification of the economy, underpinned by low-carbon power generation.
2. Create a hydrogen economy.
3. Ramp up government-led carbon pricing.
4. Advance carbon capture, utilisation and storage.
5. Focus early on harder-to-abate sectors.
Europe is a leader in climate action – pioneering innovation in new low-carbon goods and services, with significant global benefits. Important EU initiatives include a combination of targets, tariffs and financial incentives to encourage the adoption of renewable energy technologies, support innovation and investment in renewables, and stimulate research and development in clean technologies.

The benefits have been real and tangible. In recent years, wind and solar technologies have seen dramatic cost declines in Europe and beyond. By one estimate, the relatively high cost of installing solar capacity to date will be more than recovered by future cost reductions and savings, when compared to conventional thermal generation.4 Based on that estimate, France, Germany, Italy and the UK have provided a significant part of this EU global benefit. The EU has also taken the lead along with other countries in supporting the development and deployment of battery electric vehicles.

In the future, further action on new clean technologies by developed economies such as the EU will continue to be crucial to tackling climate change. These efforts act as a beacon for others, while simultaneously creating more time – and reducing the cost – for developing economies to decarbonise as well.

Achieving climate neutrality by 2050

In 2018, the EU accounted for 12% of global final energy consumption and a little over 9% of both global CO2 emissions and total global greenhouse gas emissions.5 The EU is the third largest emitter after China and the USA. However, the proportion of both final energy consumption and total production-based greenhouse gas emissions linked to the EU is expected to fall. This will happen as energy demand in Europe declines – with global energy demand growth driven by the developing world – and as the EU intensifies its efforts to reduce emissions.

This sketch focuses on CO2 emissions from the energy system, which account for more than 75% of the EU’s greenhouse gas emissions.6 It does not specifically consider most industrial process emissions, such as those created by chemical reactions used in the manufacture of cement. Nor does this sketch specifically consider land-use changes beyond their contribution as potential natural carbon sinks for energy-related emissions. Nevertheless, attention to these areas will also be essential.
Achieving climate neutrality for the EU as early as 2050 will require accelerating the energy system transition far beyond the already challenging pathway set out in Shell’s Sky scenario. Specifically, it will require unprecedented cooperation and action by EU institutions, member states, businesses and consumers working together to create a virtuous circle of change. Below we look in more detail at actions required to:

- accelerate the mass deployment of clean technologies and energies;
- target behavioural incentives; and
- remove unavoidable emissions.

ACCELERATE CLEAN TECHNOLOGIES

In the past decade, the EU has made significant progress in reducing emissions from the power sector – particularly in Denmark, Germany, Ireland, Italy and the UK, where new renewables now make up a substantial share of power generation capacity. The 2020 target for the EU to meet 20% of its total energy needs from renewables, as well as its policy support mechanisms in the form of feed-in tariffs, have driven significant renewables deployment. For instance, during most of the year it is sufficiently windy and/or sunny for Denmark to generate more power from renewables than from fossil fuels; and in Germany, renewables supplied 46% of electricity demand in 2019, up from 16% a decade earlier.

Decisions made today on infrastructure, and how it is interconnected, will have far-reaching consequences for the power sector, public transport and the emergence of lower and zero-carbon gases, such as hydrogen and biomethane.

However, a pathway to net-zero emissions by 2050 will require an acceleration not just in the deployment of familiar renewable power sources like solar and wind, but in a range of clean technologies and fuels required to decarbonise all sectors of the EU economy.
Increase electrification

Any pathway to net-zero emissions in the EU will require the economy to be electrified much more deeply, with power generated primarily from renewable sources (Figure 1). In our analysis, more than 60% of final energy demand will need to be electrified by 2050, compared to about 20% now. The electricity system will also need to more than double the size it is today. Renewables will need to account for around three-quarters of power generation, with wind becoming the largest source of electricity by about 2040, followed by solar. Coal will need to be completely phased out by 2050. The remaining natural gas in power generation will need to be equipped with CCUS, allowing it, along with nuclear, to provide power generation capacity that is not dependent on daily or seasonal weather variability and ensure security of supply.

Crucially, deeper electrification will require a fundamental rewiring of the EU economy – electrifying industrial processes, building infrastructure to electrify transport and buildings, expanding the capacity of the power grid, ramping up the scale of renewables deployment, and optimising power generation and distribution across the EU.

Figure 1: Rewiring the EU economy with low and zero-carbon electricity

Source: Shell analysis, IEA historical data
Commercialise new fuels: hydrogen and biofuels

Hard-to-electrify sectors that need portable, high-density or thermal molecular fuels will require new and clean energy sources. Early and rapid deployment of hydrogen as a fuel source will be a critical part of the solution to decarbonise some heavy road freight segments, heavy industries such as iron and steel, heating in some northern European countries, and potentially in aviation and shipping. For example, heavy-duty freight will require a combination of electrification and hydrogen fuel cells, with around 16% of the heavy truck fleet being converted to hydrogen by 2044 – equivalent to 1 million hydrogen trucks on the road (Figure 2).

Figure 2: Scaling up hydrogen

Hydrogen trucks in the EU

Source: Shell analysis, IEA historical data
In our analysis, the use of hydrogen as a fuel needs to rise from negligible levels today to about 10% of the EU’s total final energy consumption by 2050. Achieving this scale of hydrogen deployment will require significant investment in the next decade to commercialise “green hydrogen” (hydrogen produced through electrolysis powered by renewable electricity). In parallel, it will require investment in production, distribution and storage infrastructure. Most hydrogen that is produced today is made by breaking down natural gas, an established industrial process. Using natural gas to produce hydrogen does, however, create CO₂ as a by-product. If such a hydrogen production facility is teamed up with a CCUS facility – capable of storing the CO₂ produced – this can still offer a lower carbon fuel option during the early stages of the transition. Hydrogen produced in this way is known as “blue hydrogen”. Our analysis indicates that the scale of hydrogen demand, combined with growing demand for electricity, means that blue hydrogen is likely to remain part of the 2050 energy mix.

For sectors that still require high-density liquid fuels – such as long-haul aviation and chemicals – advanced biofuels will be key. They represent one of the few foreseeable low-carbon alternatives for liquid fuels by 2050. Our analysis expects biofuels use to triple between 2020 and 2050, with demand increasingly met by advanced biofuels, although limits on the availability of sustainable materials to turn into biofuels could constrain growth beyond that level (Figure 3). Moreover, given the competing uses for advanced biofuels, greater allocation of biofuels to sectors with the fewest options for decarbonisation – such as aviation – will be important for achieving net-zero emissions by 2050.
Advanced biofuels – i.e. those which minimise impact on food production as well as on the wider environment – are still some distance from being commercially viable without policy support. Policy frameworks will be required to incentivise production and drive down costs in the 2020s. Some waste-related biofuels, that are closer to commercial viability, could provide the volumes needed in the initial stages of the transition. This is particularly true in aviation.

In summary, financial support is critical for those sector-specific clean technologies and fuels that are needed to achieve climate neutrality, but which are not yet commercially viable until large-scale deployment drives down costs sufficiently. Examples include advanced biofuels in aviation and hydrogen for industry and heavy-duty freight.

In parallel, greater infrastructure planning and investment will be required, such as for low-carbon power and the transport and storage of hydrogen. In addition, there needs to be effective integration, alignment and regulation of this infrastructure across EU countries. Before deciding to invest in an element of infrastructure it is essential to understand the broader, system-wide effects of that investment decision. Gaining such understanding will allow that investment to take
In the future, the EU will need to continue to encourage significant improvements in energy use efficiency — such as more integrated urban infrastructure for transport, housing, energy, waste, water and other services.

Target Behavioural Incentives

Invest in infrastructure to improve energy efficiency

The EU economy is relatively less energy intensive than many other developed economies, with its energy intensity\(^8\) declining by 37% between 1990 and 2017. Energy demand is no longer growing in proportion to economic growth, as it has always done in the past: the size of the EU economy increased by almost 60% between 1990 and 2017, even as energy demand remained largely flat. This is because of

advantage of network effects and synergies across sectors and national boundaries. The potential to design vehicle charging networks to increase grid resilience is one example. Such considerations can ensure the delivery of efficient levels and types of new infrastructure. Ultimately, investment in infrastructure must enable the at-scale deployment and use of these new clean technologies and fuels, including adequate energy storage to secure supplies.
energy efficiency improvements and because non-industrial sectors of the economy with modest energy demands have driven economic growth.

In the future, the EU will need to continue to encourage significant improvements in energy use efficiency – such as more integrated urban infrastructure for transport, housing, energy, waste, water and other services. These measures will need to reduce energy intensity by 45% by 2050 (Figure 4).

**Incentivise and support low-carbon consumer and business choices**

The EU will need to encourage high-efficiency and low-carbon energy alternatives for consumers, such as greater use of mass public transport. Such shifts – along with efficiency improvements, low-carbon fuels and carbon sinks – in high-growth sectors like aviation, shipping and heavy road freight will be required to achieve net-zero emissions in these sectors.\(^9\)

The EU could, for example, restrict its overall energy demand in aviation to a 10% rise over 2020 levels by shifting half of the passengers

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**Figure 4: EU energy demand continues to decouple from the EU economy**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>GDP/capita</th>
<th>TFC</th>
<th>Energy intensity/capita</th>
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<tbody>
<tr>
<td>2020</td>
<td>100</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>2030</td>
<td>110</td>
<td>85</td>
<td>55</td>
</tr>
<tr>
<td>2040</td>
<td>120</td>
<td>90</td>
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<tr>
<td>2050</td>
<td>130</td>
<td>95</td>
<td>45</td>
</tr>
</tbody>
</table>

Source: Shell analysis
currently using flights over to rail for travel in Europe. Such a shift would require significant policy effort to incentivise rail travel: prioritising strategically important rail routes, investing in the necessary infrastructure and reflecting the relative carbon costs of different means of travel in the price travellers pay.

The EU will also need to encourage businesses to find new ways of operating and new business models which support low-carbon choices. This action will be essential for decarbonising entire sectoral and product ecosystems: from companies producing raw materials to those selling finished products to consumers. For example, in the road freight sector, a combination of improved logistical and operational efficiency – as well as a shift to battery electric and hydrogen fuel-cell vehicles and a shift from road to rail – will be required to decarbonise the sector. Our analysis assumes a fundamental shift from road freight to rail that reduces energy consumption in the road freight sector by more than 10% between 2020 and 2050.

Business innovation and coordination, as well as government policies, will be required to “push” new clean technologies, while low-carbon consumer choices will provide the “pull” for change.
Raise the carbon price using market and regulatory mechanisms

It is important to emphasise that the pace and cost of decarbonisation will differ across sectors. Clean alternatives are likely to reach cost competitiveness with fossil fuels in some sectors rapidly, for instance in power and passenger road transport. But other sectors are likely to require a sustained and rising carbon price in order to bridge the gap to clean technologies and fuels.

Carbon pricing mechanisms, whether explicitly via the EU Emissions Trading System or implicitly via emission standards and mandates (in sectors such as road transport, heating, buildings and appliances), will be very important. This can drive change across the economy as soon as affordable technological options are available. Our analysis assumes a rising carbon pricing mechanism – whether explicit or implicit - to more than €200 per tonne of CO₂ equivalent by 2050 to deliver and sustain the emission cuts and CO₂ management necessary for the EU to reach climate neutrality.

While carbon pricing is an efficient lever for reallocating resources and driving behavioural change, it will not be enough on its own. Complementary actions that support bringing clean technologies, fuels and products to market, as well as their deployment and diffusion at scale, must urgently continue. It is essential that policy should help provide consumers and businesses with low-carbon alternatives to adopt.
REMOVE EMISSIONS

Deploy carbon capture, utilisation and storage at scale

Carbon capture, utilisation and storage (CCUS) is essential if the EU is to achieve climate neutrality by 2050. There are several ways to apply CCUS, including new technology in development that can capture CO₂ directly from the air, or capture the emissions created during industrial processes or in those sections of industry and power generation which still need to use fossil fuels.

CCUS will play a particularly important role in decarbonising hard-to-abate sectors in industry where technology and fuel options are limited by the nature of the production process. An example is the cement industry, where CO₂ is an inevitable by-product of the chemical reactions involved in making cement.

A similarly important role exists in the power generation sector because of the potential for net-negative emissions from bioenergy combined with CCUS.

In a climate-neutral Europe, around 600 million tonnes of CO₂ per year of unavoidable emissions will need to be stored, involving the capture of just under 15% of annual emissions (based on 1990 levels) (Figure 5). Using captured CO₂ – for instance, to create synthetic fuels or chemicals – also can play an important role in the transition to net-zero. It may help displace fossil fuels and provide an additional revenue stream to support the commercialisation of CCUS.
However, captured CO₂ will eventually need to be restricted to uses which involve permanent (or near-permanent) storage, for example mineralised carbon in building materials. Many such uses of captured CO₂ remain beyond current technology and are unlikely to have a significant impact within the next 30 years.

The EU will need significant policy effort to achieve enough CCUS capacity to deal with 600 million tonnes of CO₂ per year. Actions would include, for instance, a robust and rising carbon pricing mechanism to make CCUS commercially viable. This would need to be backed up by policy frameworks that help to reduce investment risk and capital costs and manage the long-term liability associated with permanent carbon storage.

“...The need to continually add to these natural carbon sinks declines over time. The EU energy system achieves net-zero CO₂ emissions without additional reforestation from the mid-2050s...”

**Figure 5: Scaling up CCUS**

EU – CO₂ emissions captured by CCUS from all energy

<table>
<thead>
<tr>
<th>YEAR</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT CO₂ PER YEAR</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.6</td>
</tr>
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</table>

Source: Shell analysis
Determine the role of nature-based approaches

While this sketch focuses on the energy system, changes in natural systems will also affect the EU’s overall greenhouse gas emissions. Deforestation and land-use changes over the last century have released significant amounts of carbon into the atmosphere. However, forests and soils also provide natural sinks for carbon, in addition to wider environmental and social benefits.

Natural carbon sinks and technologies that permanently remove carbon from the atmosphere will be vital to deal with the most expensive and technologically hardest-to-abate emissions. The starting point for our analysis is reducing emissions from energy supply and from the sectors that are the end users of energy, as rapidly and as close to zero as possible by 2050. This relies on technologies and fuels that exist today. However, there are technological, infrastructure and behavioural constraints on how quickly they can be commercialised, scaled up and widely adopted. This will require a contribution from natural carbon sinks to achieve net-zero emissions in the next 30 years, in particular by helping to reduce overall EU emissions as harder-to-abate sectors take longer to completely decarbonise.

Even after the EU takes all the other actions described previously, natural carbon sinks will be necessary to deal with the approximately 300 million tonnes of remaining emissions from the hardest-to-abate sectors in 2050. This corresponds to the equivalent of reforesting around 5% of the EU’s land area, about 220,000 square kilometres. This is an area of landmass roughly equivalent to half the area of Spain. The need to continually add to these natural carbon sinks declines over time. The EU energy system achieves net-zero CO₂ emissions without additional reforestation from the mid-2050s.

Policy that recognises natural sinks as a way of managing emissions will be an important signal to incentivise investment in nature-based climate solutions.
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SECTION TWO

2050: A CLIMATE-NEUTRAL EU ENERGY SYSTEM
Achieving net-zero emissions in the EU within the next three decades will require fundamental structural changes to its economy and to how energy is produced and consumed across its nations.

The EU needs to change its energy mix from fossil-dominated today (71% of the energy mix) to renewables-dominated in 2050 (60% of the energy mix) (Figure 6). Our analysis also includes a 8% share of total final energy consumption coming from nuclear generation. The remaining hydrocarbons used in the EU would be limited to hard-to-abate sectors like aviation, some heavy industries and power generation – partnered with CCUS.

**Figure 6: EU energy system transformation**

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**Source:** Shell analysis, IEA historical data
In this sketch, the EU would achieve net-zero emissions by 2050, with all sectors getting as close to zero CO₂ emissions as possible. The sketch envisages carbon removal technologies and nature-based solutions absorbing the remaining unavoidable CO₂ emissions from the hardest-to-abate sectors (Figure 7). This analysis recognises that different EU countries will move at different paces of decarbonisation. For example, in our analysis Nordic countries can achieve greater than 100% emission reductions by 2050 without using additional natural sinks. The rest of north-west Europe can achieve net-zero emissions with natural carbon sinks removing around 5% of emissions (based on 1990 levels) by 2050. Other parts of Europe are slower to decarbonise.

**Figure 7: Decline in energy CO₂ emissions**

![EU - Energy related CO₂ emissions, by sector](chart)

Source: Shell analysis, IEA historical data

*Small residual net energy-system emissions by 2050 are balanced by reforestation.*
Different countries and sectors will move at different speeds, but all need to move as fast as possible.
SECTION THREE
HOW TO MAKE PROGRESS
Our EU scenario illustrates a technically possible, albeit highly challenging, pathway for the EU to achieve climate neutrality by 2050. It won’t be easy, but we believe that with widespread support and better alignment of interests the EU’s goals could indeed be reached. Here we look in more detail at how to make progress:

- A just transition – fair for all
- Sectoral coalitions for action
- Coherent and credible policy frameworks

**A JUST TRANSITION – FAIR FOR ALL**

At first sight, achieving climate neutrality in Europe by 2050 can appear both highly ambitious and expensive. However, according to our analysis, the costs to society are expected to be manageable at the macroeconomic level. There will, however, be wins and losses as the EU moves towards its low-carbon future and great effort must be made to ensure a just transition in order to secure full support from society.

Importantly, the significant realignment of economic activity and resources associated with the energy transition will not be equally spread across countries, industries and people of different economic means. The groups and sectors benefiting from the energy transition will differ from those that are disadvantaged. For example, lower income groups spend a higher share of their income on energy and can therefore be disproportionately affected by higher energy costs. Member states’ national energy and climate plans indicate limited overall effects on employment. However, the EU is likely to witness significant changes in types of employment: for example, jobs shifting from traditional to new low-carbon industries. Jobs and livelihoods will change as carbon-intensive industries retreat.

This reality means that the energy transition will inevitably create frictions and dislocations within society. Losses in the transition will undoubtedly be felt keenly. The EU’s ability to successfully manage such societal impacts will be critical if it is to ensure a smooth and rapid transition to net-zero emissions in the next 30 years. “Just” transition policies must be developed to ensure all countries, regions and income groups are able to participate in and manage the energy transition. Measures must also be

> The EU’s ability to successfully manage such societal impacts will be critical if it is to ensure a smooth and rapid transition to net-zero emissions in the next 30 years.”
Measures must be put in place to assist those who may lose their livelihoods and the regions which may suffer economic regression.

In this context, it should be noted that we estimate the cost\textsuperscript{12} of the EU achieving climate neutrality to be equivalent to reducing the absolute level of GDP by just a few percentage points in 2050, a figure dwarfed by other uncertainties in economic development. For example, 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. This is a cost that many governments see as worth paying to avoid the expected costs imposed by climate change itself. Much of this transition cost arises from greater investments needed in alternative clean technologies, in the range of €175-290 billion per year for the EU.\textsuperscript{13}

Looking back at transitions that have already been under way for some time, we estimate the cost of commercialising wind, solar and
light-duty battery electric vehicles globally to be about $2 trillion (2018) – or just over 1% of the value of the world’s capital stock in 2018. Crucially, most of these costs have already been incurred in the form of higher upfront capital costs. Ahead, there are also significant resource savings from lower operating costs still to be realised.

As manageable as these costs are, significant redirection of capital and investment towards clean technologies will still be required. Over the next 30 years, investment will be required to decarbonise the power, buildings, transport and industry sectors. The Energy Transitions Commission estimates that Europe will require additional annual investment of €150 billion between now and 2050, on top of up to €622 billion of annual average investment expected in these sectors.14 The lion’s share of additional investment will be in the buildings sector to retrofit and refurbish existing building stock (€220 billion), and in the power sector to make large-scale grid infrastructure investments (€340 billion). Investment on a smaller scale will also be required in transport to develop charging and refuelling infrastructure, and in industry to retrofit existing plants and build new low-carbon facilities.

The estimated additional €150 billion annual investment is broadly comparable to the €1 trillion (in public and private funds) that the European Commission is seeking to mobilise as part of the Sustainable Europe Investment Plan to finance the Green Deal over the next 10 years. Part of the plan, the Just Transition Mechanism, is focused on delivering a fair and just green transition, mobilising at least €100 billion in investments over the period 2021-27. 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.
The entire ecosystem of each sector of the economy will need to come together to pursue net-zero emission pathways.

SECTORAL COALITIONS FOR ACTION

As noted previously, for the EU to achieve climate neutrality as early as 2050 will require it to accelerate the energy system transition beyond the already challenging pathway set out in Shell’s Sky scenario. Specifically, it will require unprecedented cooperation. A very significant part of that unprecedented cooperation will need to involve businesses collaborating to form coalitions for action.

Transforming the EU’s energy system means everybody making greener choices: from individuals, to companies, to governments. These choices must be made easier for people. And while some of the answer comes down to governments, as detailed in the next section of this sketch, it is not all down to governments.

Alongside governments, businesses have a significant role to play – businesses which supply energy, alongside those in sectors that use energy, such as shipping, buildings, aviation, chemicals, steel and cement. The entire ecosystem of each sector of the economy will need to come together to pursue net-zero emission pathways.

The actual action needed in each sector will vary, but all sectors share the same three ways to make progress. First, improve energy productivity by making more energy-efficient choices. Second, turn to lower-carbon energy products. Third, remove or store emissions that cannot be avoided.

The ecosystem around each industry must come together and work out how to take action in each of those three areas to achieve net-zero emissions. Once proposed pathways are established, the ecosystems can seek to work with governments to clear any obstacles to making progress.
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 such pathways are embedded and widely supported. This points to a need for policies that systematically address barriers to change, such as maintaining international competitiveness and lack of coordination between key players – especially in sectors that are harder to electrify and hence to abate. This requires greater coordination between sector-specific policies, sequencing these policies to create markets and demand for lower-carbon energy products, as well as time-limited financial support to make those products commercial and bring them to market.

Successful coalitions of this kind will inevitably need to reach beyond the borders of the EU. But establishing such coalitions will require pioneer businesses – and governments – to lead the way for others to join.

A good example of this pioneer approach is the Global Maritime Forum’s Getting to Zero Coalition announced at the UN Climate Summit in New York in September 2019. It started with fewer than half a dozen businesses but now brings together more than 90 companies to find a way to put a commercially viable net-zero emissions ship to sea by 2030. Today it includes companies from every part of the shipping ecosystem: shipbuilders, logistics, ports, fuel suppliers, ship operators, heavy freight customers, regulators and banks.

COHERENT AND CREDIBLE POLICY FRAMEWORKS

Policy has a fundamental role in driving the energy transition to net-zero. It can speed up technology development, commercialisation and diffusion 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 encourage shifts in consumer mindsets (Box 1, page 32). Based on our analysis, achieving climate neutrality will require policy frameworks that are:

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

Success will depend on implementing policies that give appropriate encouragement to pioneer companies. Long-term policy clarity and legal certainty, both around the 2050 target and the process for monitoring and ensuring progress towards that target, will help to incentivise the large upfront capital investment needed.

It is also highly likely that other regions of the world which compete with the EU will not have comparably stringent climate policies. This dynamic means that additional measures will also be needed to protect competitiveness and prevent certain industries from shifting to parts of the world with weaker approaches to climate change – so called carbon leakage. These additional measures could include, for example, carbon border adjustments for some sectors.

Article 6 of the Paris Agreement provides a key platform to foster greater international cooperation. It has the potential to drive climate action at faster and larger scale and deliver a more cost-effective transition to climate neutrality. Article 6 should be implemented in a way that does not undermine the integrity of carbon credits. It should be designed to prevent carbon credits 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. A recent study by the University of Maryland commissioned by the International Emissions Trading Association (IETA) found that international cooperation could deliver savings of $250 billion a year by 2030, which could be reinvested in additional climate action.15
COMPREHENSIVE AND ECONOMY-WIDE

1. **Set clear and binding legislative targets.**
   This helps increase policy certainty to support the substantial and long-term investment required for the energy transition. It should include intermediate targets for 2030 and 2040 based on a cost-effective net-zero emissions pathway.

2. **Expand carbon pricing across the economy.**
   This can be done explicitly via the EU Emissions Trading System and energy and/or carbon taxes. This can also be done implicitly via sector-specific emissions and efficiency standards which indirectly create demand for, and stimulate investment in, clean energy technologies. Over time the carbon price should increase, such as through a rising tax on carbon or a progressive tightening of the EU ETS cap and emissions and efficiency standards. The EU will need to include safeguards and innovation support to ensure European industry remains competitive and early movers are rewarded.

3. **Support infrastructure investment.**
   This enables at-scale deployment and adoption of clean technologies and fuels, and development of integrated infrastructure across sectors, technologies and fuels. For example, investments should be made or encouraged in smart power grids, hydrogen infrastructures and the rail system.

4. **Increase the pace of progress towards the EU energy single market.**
   This is particularly important for expanding and decarbonising power and for the adoption of clean fuels like hydrogen.
COHERENT WITHIN AND ACROSS SECTORS

5. Allocate time-limited financial support.
As far as possible, this should be through competitive auctions or other mechanisms to ensure the efficient use of resources. This can accelerate the development and commercialisation of clean technologies and fuels in specific hard-to-abate sectors.

6. Address barriers to greater efficiency.
This is critical for improving the energy efficiency of residential and commercial buildings and to support greater materials efficiency across industries and products.

7. Overcome coordination problems.
Better cooperation and coordination across value chains is fundamental to accelerate the adoption of efficient and clean processes, technologies and fuels. For example, between airport, airline and aviation fuel suppliers to speed up the commercial-scale production and adoption of sustainable aviation fuels.

8. Establish governance around the role of natural emissions sinks.
This will be important to manage emissions from fast-growing and harder-to-abate sectors like aviation as decarbonisation solutions are commercialised and adopted.

CREDIBLE AND PREDICTABLE OVER TIME

9. Lay the foundations for a just transition.
To make progress at pace, the energy transition needs to be equitable and fair. It is critical to plan and manage any adverse consequences of change for those that experience this.

10. Encourage wide societal participation in change.
Promote a wider understanding of the benefits of the energy transition to encourage and embed long-term environmentally sustainable behaviours and choices.
The EU has set its target: climate neutrality by 2050. It is an important step for Europe, a pioneering moment for the world and an ambition Shell wholeheartedly supports. In many ways it is the logical next move for a region that has long taken the lead in tackling climate change.

And in many ways the EU is the best placed region to launch an ambition as bold as this: it already has much experience and has learned numerous lessons that position it well. Europe has already invested heavily in technologies like wind and solar and can now hope to reap some of the rewards of that early investment as these technologies spread and scale up.

But the EU is not currently on a course to achieve climate neutrality by 2050. There is much work to do. Achieving the stretch goal of the Paris Agreement remains technically possible, but the required pace of change is highly challenging, even for a region with the head start, economic strength and determination of the EU. Moreover, it will require a substantial effort to ensure the EU meets its goal of climate neutrality at the same time as financing a just transition to bring all sections of society along with the changes to come.

As this sketch has explored, very rapid action is needed in many areas: from the spread of electrification and renewables
to the substantial adoption of new fuels like hydrogen and advanced biofuels; from the need for governments to raise progressively the effective carbon price to the necessity of protecting the EU’s competitive position in a world that is changing at a different pace; from radically shifting consumption patterns and consumer attitudes to dramatically increasing the efficiency with which energy is used. And, as the EU undertakes all that work, dealing with the unavoidable and harder-to-abate emissions that remain, either through technological solutions to capture and store CO₂, or through nature.

There is, indeed, a lot that must be done, and time is short. But we believe the costs of the transition are manageable and much of the technology required for success is already at hand. And success is within the EU’s power to achieve.

It is within the EU’s power to ensure that progress happens in a way that is fair. It is within the EU’s power to encourage the pioneer businesses and clear the way for the sectoral decarbonisation pathways they identify. And it is within the EU’s power to design its policies to align and maximise the push to decarbonise.

The EU has a proud history of leadership in climate change. Its ambition to achieve climate neutrality by 2050 puts the EU in a position to lead in the decades to come. And although it faces many challenges to overcome, not least recovering from the impact of the 2020 pandemic, the EU appears well equipped to succeed.
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td><strong>Advanced biofuels</strong></td>
<td>Liquid biofuels produced from non-food crops, including forest products. Also called cellulosic biofuels or second-generation biofuels.</td>
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<tr>
<td><strong>BECCS</strong></td>
<td>Bioenergy with carbon capture and storage.</td>
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<tr>
<td><strong>Carbon price</strong></td>
<td>Throughout this sketch, the term carbon price is used to refer to a government-led carbon pricing mechanism via a tax, an emissions trading scheme or regulatory standards.</td>
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<tr>
<td><strong>CCUS</strong></td>
<td>Carbon capture, utilisation and storage.</td>
</tr>
<tr>
<td><strong>Energy productivity</strong></td>
<td>Measures the output produced from a unit of energy. It is calculated as total output (as measured by GDP) divided by the total primary energy consumed in a given year.</td>
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<tr>
<td><strong>First generation biofuels</strong></td>
<td>Liquid biofuels produced from crops, derived from the sugar, starch or oil components. Biofuels from oils from animal products are included in wider definitions of first generation, but these are not in the scope of our analysis.</td>
</tr>
<tr>
<td><strong>EU ETS</strong></td>
<td>EU Emissions Trading System.</td>
</tr>
<tr>
<td><strong>Final energy</strong></td>
<td>The demand for energy carriers, such as electricity or liquid fuels, by final consumers (such as industry, households and transport) for all their energy uses. When natural gas is used for home heating, it is counted as final energy; when it is used to generate electricity in a power station, it is counted as primary energy.</td>
</tr>
<tr>
<td><strong>Nature-based solutions</strong></td>
<td>Nature-based solutions provide natural carbon sequestration by protecting or developing natural ecosystems, such as forests, grasslands and wetlands.</td>
</tr>
<tr>
<td><strong>Nationally determined contributions</strong></td>
<td>The actions countries take to reduce greenhouse gas emissions under the Paris Agreement.</td>
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<tr>
<td><strong>Net-zero emissions</strong></td>
<td>A balance between anthropogenic emissions by source and the removal of greenhouse gases by carbon sinks.</td>
</tr>
<tr>
<td><strong>Primary energy</strong></td>
<td>The supply of energy sources including oil, natural gas, coal, bioenergy, nuclear energy and renewables. Primary energy is energy drawn from nature, in its first usable form.</td>
</tr>
<tr>
<td><strong>Renewables</strong></td>
<td>Defined as wind, solar, hydropower, geothermal and bio-resource.</td>
</tr>
<tr>
<td><strong>Solar</strong></td>
<td>Solar photovoltaic panels used for power generation. Solar energy includes both centralised (e.g. solar farms) as well as decentralised (e.g. residential rooftop) photovoltaics and concentrated solar power (thermal installations).</td>
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</tbody>
</table>
ACKNOWLEDGEMENTS

We wish to thank the many people consulted externally in the development of this work. Particular thanks go to The Nature Conservancy. This work is partially based on historical data from the International Energy Agency’s (IEA). The work has been prepared by Shell International B.V. and does not necessarily reflect the views of the IEA.

ENDNOTES

1 Shell supports the EU’s 2050 climate neutrality target and the EU Climate Law.

2 International Energy Agency data.

3 For the purposes of this work, the EU is understood to include the UK, as the work was initiated when the UK was still a full member. The EU aggregates in this sketch include the 27 EU member states and the UK for data consistency over time. Both the EU and UK have made commitments to reach climate neutrality and net-zero emissions by 2050, and the UK commitment became legally binding in 2019.


5 Shell analysis, IEA historical data.

6 European Environment Agency and International Energy Agency


8 The ratio between the total energy demand for the region and its gross domestic product (GDP).

9 Sweden saw a 4% drop in flights taken in 2019 compared to the year before (a 9% reduction in domestic flights), partly attributable to climate concerns and policies.

10 Shell’s World Energy Model is in USD. For this sketch a conversion to EUR is referenced (1.11 USD/EUR) based on the 2019 average exchange rate.

11 We calculate this to require the equivalent of opening two CCUS plants the size of Shell’s Quest CCUS facility in Canada every month from 2025; Quest captures 1 MtCO2e annually.

12 These costs refer to the additional resources required to meet the target, e.g. as a result of clean or low-carbon technologies being more expensive than the fossil-based technologies they replace and crowding out other more productive investments as a result.

13 “A Clean Planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy” (2018), page 16.


15 The Economic Potential of Article 6 of the Paris Agreement and Implementation Challenges by IETA and Carbon Pricing Leadership Coalition (CLPC).
On March 4, 2020, the EU Commission proposed the European Climate Law that would establish a legally binding target of net-zero greenhouse gas emissions by 2050. Shell strongly supports the proposed European Climate Law and its binding target of net-zero greenhouse gas emissions by 2050.

We believe meeting this target will be extremely challenging but possible. This report contains an assessment of what we believe may be needed to decarbonise the energy system in order for the EU to meet the proposed target of net-zero greenhouse gas emissions by 2050. This overview is not intended to be prescriptive and there are other pathways for the EU to follow in reaching the target. It is important to note that the suggestions contained in this report are those to be taken by the EU, and not necessarily Shell. While Shell is supportive of the EU target of net-zero greenhouse gas emissions by 2050, our current business plan is not consistent with the proposed EU target. However, as announced on April 16, 2020, Shell aims to be a net-zero emissions energy business by 2050. Accordingly, we expect that over time, our business plan will change as society and our customers move toward meeting the goals of the Paris Agreement. We believe that the proposed European Climate Law is a significant step in this journey.

The companies in which Royal Dutch Shell plc directly and indirectly own investments are separate legal entities. In this report “Shell”, “Shell Group” and “Royal Dutch Shell” are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words “we”, “us” and “our” are also used to refer to Royal Dutch Shell plc and its subsidiaries in general or to those who work for them. These terms are also used where no useful purpose is served by identifying the particular entity or entities. “Subsidiaries”, “Shell subsidiaries” and “Shell companies” as used in this report refer to entities over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to as “joint ventures” and “joint operations”, respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as “associates”. The term “Shell interest” is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in an entity or unincorporated joint arrangement, after exclusion of all third-party interest.

This report contains forward-looking statements (within the meaning of the U.S. Private Securities Litigation Reform Act of 1995) concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management’s current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management’s expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as “aim”, “ambition”, “anticipate”, “believe”, “could”, “estimate”, “expect”, “goals”, “intend”, “may”, “objectives”, “outlook”, “plan”, “probably”, “project”, “risks”, “schedule”, “seek”, “should”, “target”, “will” and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this report, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell’s products; (c) currency fluctuations; (d) drilling and production results; (e) reserve estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; (m) risks associated with the impact of pandemics, such as the COVID-19 (coronavirus) outbreak; and (n) changes in trading conditions. No assurance is provided that future dividend payments will match or exceed previous dividend payments. All forward-looking statements contained in this report are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell’s Form 20-F for the year ended December 31, 2019 (available at www.shell.com/investor and www.sec.gov). These risk factors also expressly qualify all forward-looking statements contained in this report and should be considered by the reader. Each forward-looking statement speaks only as of the date of this report, April 16, 2020. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this report.

We may have used certain terms, such as resources, in this report that the United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. Investors are urged to consider closely the disclosure in our Form 20-F, File No. 1-32575, available on the SEC website www.sec.gov.