STATKRAFT'S LOW EMISSIONS SCENARIO 2020

Statkraft

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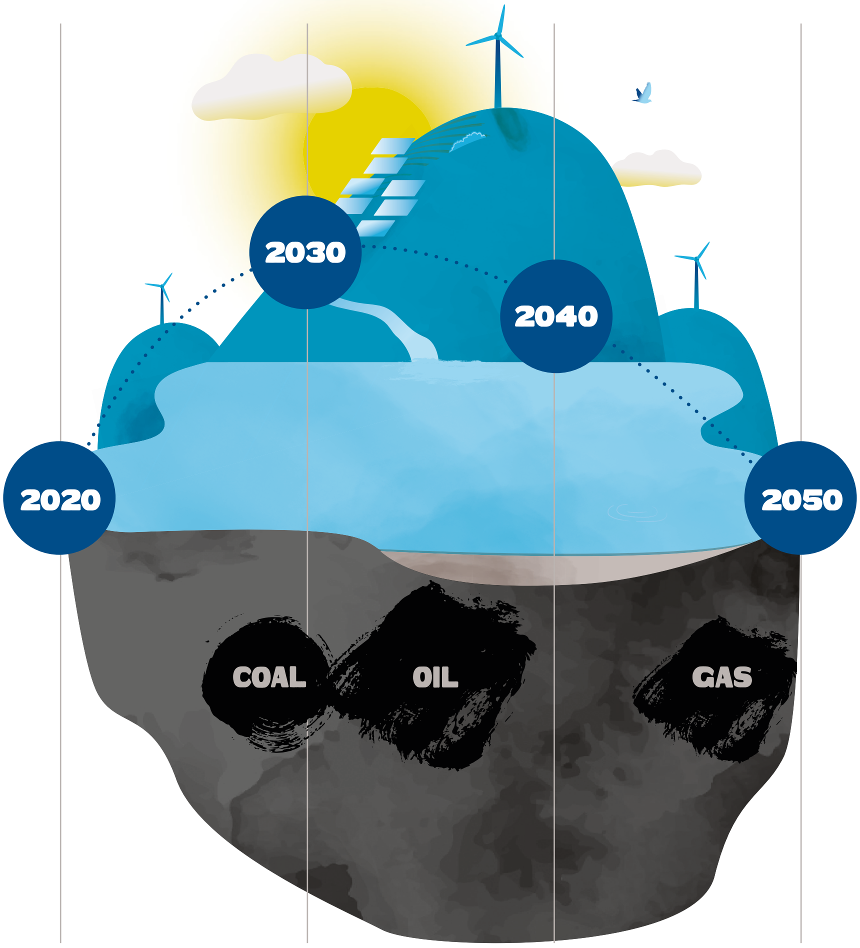
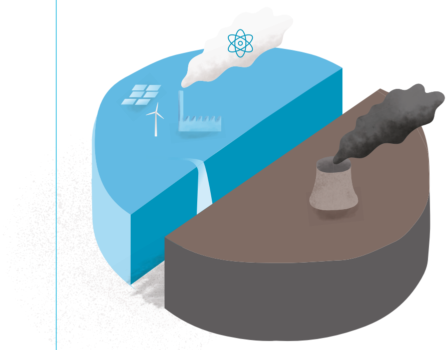


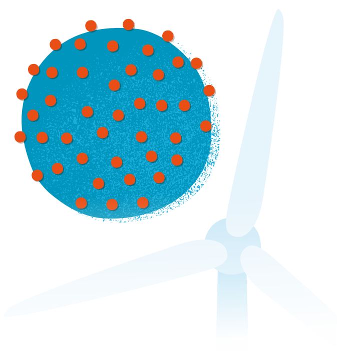
The demand for primary energy will be at the same level in 2050 as it is today. It will increase towards 2030, then level off before falling as 2050 approaches. This will happen even with continued growth in the population and the economy.

All fossil fuels will be affected by the energy transition, but at different times. The demand for coal will peak before 2025. Oil demand will peak five to seven years later, and natural gas demand will peak towards the end of the period.

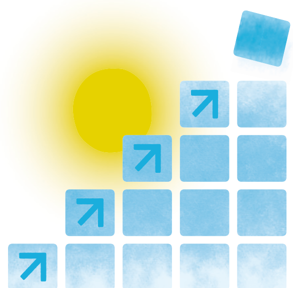


2019 was the first time in decades when electricity demand increased, while fossil fuel-based electricity generation decreased, and the first year that renewable electricity generation together with nuclear power outpaced coal-fired electricity generation.

All new passenger cars will be electric in 2050, and almost 60% of new heavy vehicles will be powered by battery or hydrogen.



The COVID-19 crisis has affected renewable energy the least: Renewable energy looks set to be the only source of energy to experience production growth in 2020 despite the pandemic, albeit lower than expected prior to the outbreak of the coronavirus.



In the Low Emissions Scenario, the capacity in the global power sector will increase three-fold between now and 2050. The entire increase, and more besides, will be covered by renewable energy (GW). Solar PV will be the largest source of power generation from 2035.

As costs for renewable power decline, decarbonisation through electrification will become increasingly attractive. Electrification will cut emissions significantly in buildings, industry and transport.

SUMMARY OF STATKRAFT'S LOW EMISSIONS SCENARIO 2020

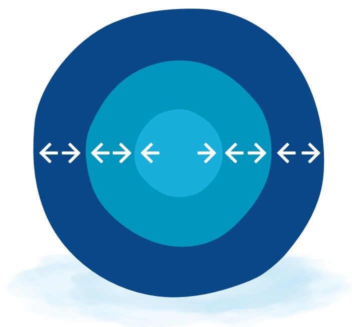
Statkraft's Low Emissions Scenario is developed by Statkraft's strategic analysis team in cooperation with experts in other fields. Over 50 colleagues are involved in market analysis at Statkraft. An overview of key parameters and assumptions in the Low Emissions Scenario is presented in the Appendix, page 56.

Energy-related CO_2 emissions will follow a two-degree pathway.

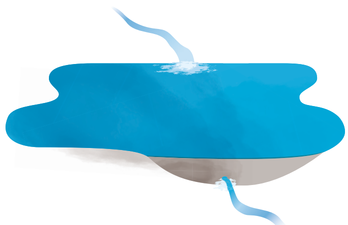
Effective carbon pricing coupled with an ambitious climate policy will accelerate the energy transition and reduce emissions quicker than an ambitious climate policy alone.

Predictable climate ambitions and regulatory frameworks are necessary for an effective transition of the energy system. Delayed and unpredictable climate ambitions will lead to unwise investments and a more costly transition.

Emission-free hydrogen in different forms (including ammonia) will play an increasing role in applications where direct electrification is a challenge.



The energy system of the future will be closely integrated and lead to a complex interaction: electricity and emission-free hydrogen in different forms will be pivotal, and the dynamics between the different sectors will be important.



The large share of variable renewable power production will require sufficient flexibility to balance the power system and avoid major power price variations.
Batteries, flexible demand and flexible hydrogen production are alternatives under development. Today, flexible hydropower is the only renewable alternative – where it is available – that provides flexibility in both the short- and long-term at an acceptable cost.

THE ENERGY TRANSITION IN AN UNCERTAIN WORLD

The COVID-19 pandemic has put the world on hold. We are travelling less and spending less. The pandemic has hit fossil energy the hardest. Renewable energy sources are the only sources to be experiencing production growth in 2020.

2019 was the first year in several decades in which the global demand for power increased, while fossil fuel-based electricity generation decreased. It was also the first year that renewable electricity generation together with nuclear power outpaced coal-fired electricity generation.

In 2020, the COVID-19 pandemic followed by infection control measures put the world on hold. The outcome so far has been striking: Renewable energy are the only sources of energy to experience production growth.

Greater uncertainty

The uncertainty in the global economy has intensified dramatically with COVID-19. How the world tackles the pandemic and how the economies recover will also affect the global energy markets for a long time to come. A fundamental question for the energy markets is whether the pandemic will accelerate or decelerate the green transition.

In a time of great uncertainty, envisioning future scenarios is even more relevant in order to obtain a better insight and inform the decision-makers. This is the fifth year in a row we present our Low Emissions Scenario. The scenario is also this year based on an evolution of known technologies and assumes an optimistic and realistic continuation of current trends in renewable and clean technologies towards 2050*. The scenario assumes that the global effort to solve the climate crisis will continue after the COVID-19 pandemic. The scenario assumes a political commitment to facilitating rather than hindering the energy transition, as well as adequate mobilisation of private capital. This means that market, technology and policy will reinforce each other and essentially move in the same direction.

Solar PV greatest from 2035

In this year's Low Emissions Scenario, we take into account lower economic growth as a result of the COVID-19 pandemic. This, combined with significant electrification and energy efficiency improvements, means that the energy demand in 2050 will be at the same level as today**. We see that in countries with good solar or wind resources it is already profitable to install new renewable capacity rather than new fossil capacity.

New solar and wind power will also increasingly outcompete existing coal or gas power. Solar PV will be the largest power generation technology globally as early as 2035. The outcome will be a restructured global energy system, where the sectors are closely integrated through electricity and emission-free hydrogen. Demand for coal and oil will decline globally, and demand for natural gas will level off before starting to decline towards the end of the period. This year, as last year, global energy-related CO_2 emissions in the Low Emissions Scenario will be in line with a two-degree pathway.

What can hinder the transition?

Since the United States chose to withdraw from the Paris Agreement, the EU has taken a higher responsibility for the momentum in global climate politics. The EU sets ambitious climate targets, followed-up with detailed measures through its new growth strategy, the European Green Deal. This is underpinned by the work in recent years to establish well-functioning, integrated energy markets. Last year, we undertook an in-depth analysis of what is needed for energy-related emissions to follow a 1.5-degree pathway. This year, we have analysed in depth the potential consequences for the transition and alternative solutions if Europe encounters various barriers. We recognise that the choice of climate ambition and policy instruments will affect the pace and costs of the transition. The analyses show that even if we assume significantly lower economic growth, and even with various barriers to the energy transition, we will still see significant growth in renewable energy in Europe and globally, as well as a strong focus on electrification and emission-free hydrogen.

*The Low Emissions Scenario is based on known technologies and on Statkraft's own global and regional analyses. The analyses are based on internal models as well as in-depth studies of external sources. The scenario is not based on a linear projection of current trends, nor does it base itself on a given climate target and perform a backward analysis from this.

**This refers to primary energy, which is the direct amount of energy at the source that has not been subjected to any conversion or transformation process. See the detailed explanation in information box 6 in the report.

1

THE ENERGY WORLD IS CHANGING

650

The world's glaciers have lost over 650 gigatonnes of ice per year since 2006

7

7 million people die from air pollution every year

1/4

The ocean has absorbed around a quarter of the annual CO_2 emissions since 2009

THE ENERGY WORLD IS CHANGING

As we enter a new decade, it is natural to take a step back before envisaging the road ahead. Climate change is happening faster and more intensely than was generally expected a few years ago. There is more extreme weather, the pace of ocean warming is accelerating and the sea level is rising. The visible consequences make it easier to gain political support for the energy transition. Meanwhile, local opposition to specific climate measures has shown the importance of an equitable distribution of costs and benefits of the energy transition across regions, countries and social groups.

In this part of the report, we take a brief look back at climate and energy trends over the past years. We discuss the role of international climate negotiations and how Europe's leading climate position has been evident during the COVID-19 pandemic. The next chapter extends some of these climate and energy trends to 2050 in Statkraft's Low Emissions Scenario. The last part of the report takes an in-depth look at Europe towards 2050 and discusses the factors that could weaken or strengthen the pace and direction assumed in the Low Emissions Scenario.

In 2020, climate was ranked as one of the biggest global risk factors, both in terms of probability and consequences, before the COVID-19 pandemic took the world by surprise[1]. The climate crisis and the COVID-19 crisis have some common characteristics; they both require an urgent solution, they are global crises that essentially have to be dealt with regionally, they are complex with unforeseeable consequences, and they are difficult to delimit in time or space[2].

As a consequence of the COVID-19 crisis, the International Monetary Fund now expects a decline in the global economy of 4.9% from 2019 to 2020. This will be the deepest economic crisis since World War II. The pandemic will likely cause many millions of people to fall back into poverty[3]. The spread and management of the pandemic, both in terms of health and economy, will impact the global community and energy markets for a long time to come, and 2020 may become a global tipping point. Against a backdrop of increased political tensions and lower economic growth, the global balance of power is changing. The world's economic epicentre is gradually shifting towards Asia. Being able to exert greater economic muscle also enables a country to demand more political influence, and we are seeing an escalating rivalry between the United States and China. The pandemic and political tensions will have an impact on the global energy situation.

New insights on climate change as the consequences become more visible

Man-made greenhouse gas emissions continue to increase. The consequences of climate change are becoming more visible. The COVID-19 pandemic and the resulting lower economic growth and energy demand result in a temporary decline of CO_2 emissions from energy this year.

As climate change has become more visible in the last decade, we have constantly been gaining new insight into the correlation between man-made emissions and climate change. In 2019, the UN Intergovernmental Panel on Climate Change (IPCC) released two special reports that presented new evidence in connection with land, oceans and the cryosphere[4]. The new evidence shows that:

- Changes to forestry, agriculture and land use have contributed around 23% of man-made greenhouse gas emissions since 2007
- In addition, ocean warming is now happening twice as fast as was the case 25 years ago
- The last five years have been the warmest, and every decade since 1980 has been warmer than any previous decade since 1850
- Since 2009, the ocean has absorbed around a quarter of the annual CO_2 emissions and thus limited the increase of CO_2 in the atmosphere. However, increasing the amount of CO_2 in the ocean will reduce the pH value, which makes the ocean more acidic. Sea levels continue to rise at an accelerating pace and in 2019 reached their highest level since 1993. This is due to both increased deglaciation and the fact that the sea expands as the temperature increases[5]
- In the Barents Sea, ice cover has halved in the last 40 years, and Greenland, Antarctica and other glaciers have lost over 650 gigatonnes of ice per year since 2006[6]. The volume of the annual ice loss is equivalent to 670 000 times the Empire State Building in New York.

EXTREME WEATHER, DEGLACIATION AND OCEAN ACIDIFICATION

INCREASED AMOUNT OF CO_2 IN THE OCEAN

Increased amounts of CO_2 in the ocean reduces the pH value and makes the ocean more acidic. Sea levels continue to rise at an accelerating speed and in 2019 reached their highest level since 1993.
This is due to both increased deglaciation and the fact that the sea expands as the temperature increases.

670 000 TIMES THE EMPIRE STATE BUILDING

Greenland, Antarctica and other glaciers have lost over 650 gigatonnes of ice per year since 2006. The volume of the annual ice loss is equivalent to 670 000 times the Empire State Building in New York.

TROPICAL CYCLONE IDAI

The tropical cyclone Idai hit South Africa's east coast in spring 2019. Between January and June 2019, more than 6.7 million people were evacuated due to extreme weather.

Extreme weather is becoming more frequent, and causes extensive damage[7]:

- Between January and June 2019, more than 6.7 million people were evacuated due to extreme weather.
- Australia, India, Japan and Europe all had record-high temperatures. Two heat waves hit Europe in the summer of 2019, resulting in more than 4,000 fatalities.
- Hurricane Dorian hit the Bahamas and North America in the autumn of 2019, causing damage of more than USD 3.4 billion.

Man-made greenhouse gas emissions continue to rise as the consequences become more visible. The energy-related CO_2 emissions have increased every decade from less than 12 gigatonnes per year in the 1960s to almost 35 gigatonnes in 2018 (figure 1)[8, 9]. 2020 is a unique year in that we expect falling emissions as a consequence of the COVID-19 pandemic. Experience from previous crises shows that a decline in CO_2 emissions due to the pandemic may be a temporary phenomenon that is replaced by an increase if no permanent structural changes take place in society[10].

In addition to greenhouse gas emissions, local air pollution is a growing problem. Approximately 7 million people die worldwide from air pollution every year[11]. At the same time, 840 million people still lack access to electricity and 2.6 billion people lack access to clean cooking facilities[12].

From Copenhagen to Paris to Glasgow: a new decade of climate negotiations

Since the 2000s, we have been through two decades of climate negotiations. 2020 is a crucial milestone: this year sees the implementation of the Paris Agreement, in which 188 countries have committed themselves to national climate targets.

A global crisis is best solved with global cooperation. The international climate negotiations of UNFCCC are an important arena. One tangible result of the climate negotiations is the Paris Agreement, which is set to be implemented this year. This will make 2020 a historically important year.

The start of the decade was marked by the climate summit in Copenhagen in 2009 not meeting expectations. In the absence of a new binding international agreement, it was decided in 2012 to extend the Kyoto Protocol until 2020. A turning point came in 2015 when there was broad agreement on the Paris Agreement, and as of today, 189 countries have ratified the agreement[14]. The agreement contains several important decisions, including that the countries will work to limit global warming to well below 2 degrees Celsius and down to 1.5 degrees Celsius. The Paris Agreement committed all countries to national climate targets, whereas only 34 countries were obliged to limit their emissions under the Kyoto Protocol. The United States has subsequently decided to withdraw from the Paris Agreement, which will be implemented on or after 4 November 2020. None of the other 188 countries have chosen to follow the United States. The next presidential election in the United States is to be held on 3 November 2020. The outcome of the election can potentially have a significant effect on global climate politics. The two presidential candidates have opposite views when it comes to climate policy and international cooperation. A change in the US presidency could therefore have a major impact on the pace of the global energy transition.

The COVID-19 pandemic has led to restrictions on large gatherings, and this year's climate summit in Glasgow has therefore been postponed until the autumn of 2021. Some areas of the Paris Agreement are still being negotiated, including rules on how countries can work together to achieve climate targets and the use of market mechanisms. All countries will update and reinforce their targets in 2020, and an evaluation will be carried out every five years to assess if we are on track to reach the Paris Agreement targets. How this five-year reinforcement mechanism works will to a large extent determine whether the Paris Agreement is effective and whether the global community manages to limit global warming to well below 2 degrees.

Climate remains high on the European political agenda

The EU has taken on a leading role in global climate policy and is increasingly encompassing all parts of the economy in its European Green Deal growth strategy. The ambition is net zero greenhouse gas emissions by 2050.

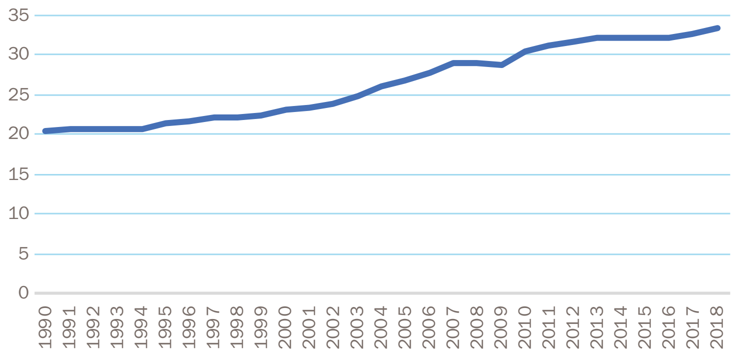
The international climate negotiations and the Paris Agreement have been important premises for the European climate and energy policy over the past decade. Ahead of the Copenhagen summit in 2009, the EU adopted a 20% climate target for 2020 (from

840
million people lack access to electricity

189
countries signed up to the Paris Agreement

30%
of the EU's long-term budget and crisis package totalling EUR 1,824 billion will be earmarked for climate measures

1 Energy-related CO_2 emissions globally since 1900 (Gt CO2/yr) [13]



1990 levels). This target was already reached in 2018. Ahead of the Paris Summit in 2015, the EU adopted the climate target of a 40% reduction in emissions for 2030 (from 1990), which is currently proposed strengthened. The requirement for a long-term climate strategy in the Paris Agreement has contributed to the EU developing the ambition of net-zero emissions by 2050.

To reach net-zero, climate policies and measures must encompass all sectors. This is clearly reflected in the European Commission's proposal for a new growth strategy, the European Green Deal[15].

At the heart of the strategy is an ambition for the EU to be climate neutral by 2050, a proposal to raise the 2030 target and a proposal for the first European climate law in history. These will set the direction for all the other initiatives in the strategy.

A transition to an economy with zero emissions in 2050 will require deep changes throughout society. The European Green Deal is therefore far more comprehensive than the European Commission's previous climate proposals, and it combines a reinforcement of market solutions with a strategic industry focus and a commitment to a socially just transition.

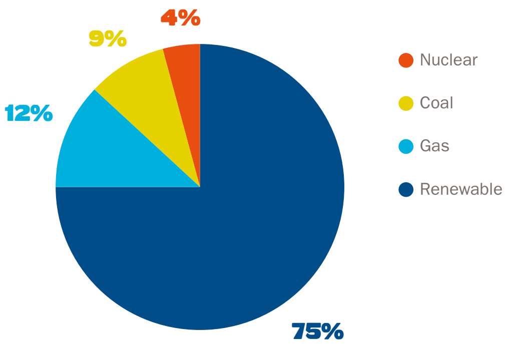
By adopting such a holistic approach, the Commission hopes to enable a faster transition that is both economically and socially sustainable.

In July 2020, the Commission presented a sector coupling strategy for smarter energy use across sectors. The most important measure is to electrify as much of the energy consumption as possible and replace fossil fuels with renewable energy. There is a large potential for electrification in buildings, industry and the transport sector. There is also a focus on emission-free hydrogen as an important energy carrier for areas of application that are difficult to electrify. Among other elements, the European Green Deal includes a new industrial strategy, a circular economy action plan, a just transition fund, a proposal to strengthen the emissions trading system and changes in energy taxation.

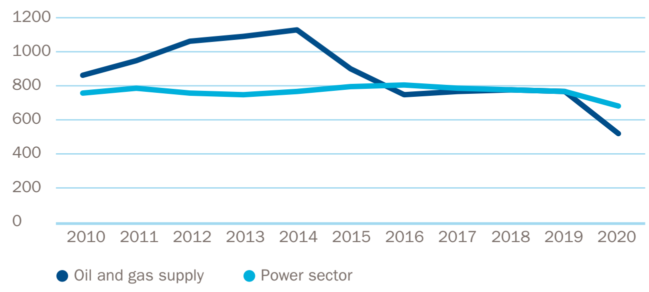
The flagship climate policy instrument continues to be the European emissions trading system. The more ambitious climate targets will require improvements to the emissions trading system in order to ensure a cost-effective transition. As part of the European Green Deal, it will be assessed whether the emissions trading market should expand to more sectors, such as transport and heating.

The partial economic shutdown due to the COVID-19 crisis led to a 12% drop in eurozone GDP in the second quarter of 2020[16]. There is a risk that this could slow down the energy transition. However, the proposed EU recovery plan and long-term budget with 30% earmarked for climate could facilitate the implementation of the European Green Deal, making it easier to meet future targets[17]. In France and Germany, parts of the recovery packages support the automotive industry moving in a greener direction. These are examples of measures that can accelerate the energy transition.

2 Global investments in new power production 2019[18]



3 Global investments in energy supplies (USD billion) estimates for 2020 are preliminary.[22]



Investments are shifting from fossil to renewable energy

The financial market has emerged as a key driver in the energy transition. Huge investments in renewable technologies have resulted in installed capacity for wind power quadrupling in the last ten years, while solar PV has seen a 27-fold increase.

With a growing understanding of climate risk and implications for investments, the financial market has emerged as a key driver of the energy transition. Investments of USD 2,600 billion in new renewable technologies over the last ten years have contributed to a quadrupling of installed capacity for wind power, while solar PV has seen a 27-fold increase globally[19]. In 2019, three-quarters of all investments in the power sector went to renewable energy (Figure 2). Since 2015, investments in the power sector have been higher than or equal to investments in oil and gas supplies globally. Even with growth in production and installed capacity of renewable power, the large fall in costs for solar and wind power in recent years has meant that the amounts invested in renewable power have been quite stable during the period. The trend in oil and gas investments globally has been declining in recent years according to the IEA, and as a result of the COVID-19 crisis they are expected to be significantly below the global investments in the power sector in 2020 (Figure 3)[20].

The pandemic is expected to reduce the total investment in energy by a fifth in 2020 compared with 2019. Fossil fuels have been hit the hardest, and the oil and gas sector is taking the biggest hit, with an estimated loss of almost USD 250 billion. This corresponds to a third of the investment volume from 2019. The power sector has not been affected to the same extent, but nevertheless a decline of around 10% is expected this year as a result of the partial shutdown of society and disruptions in supply chains globally. In 2019, 20% of all new solar capacity was built on rooftops of a residential or commercial building. This activity slowed significantly in the spring of 2020. Wind power is expected to be less impacted, especially due to some financial support schemes in the US and China requiring wind farms to be connected to the grid by the end of the year. Some delays in project implementation and investment decisions have also been observed in solar PV and wind power this year, and the forecasts are still uncertain[21].

2019 was the first year when renewable and nuclear electricity generation reached the same levels as coal-fired power globally. This made 2019 the first year in decades that fossil fuel-based generation declined globally while overall electricity generation increased[23].

As a result of COVID-19, the global demand for electricity fell by 2.5% in the first quarter of 2020 compared to 2019. During the year, consumption may fall by as much as 5% globally, which would be the largest decline since the stock market crash in 1929. Coal power production has been reduced the most, and is down 8%. This is also caused by the current record-low gas prices, which make it more profitable to run gas power than coal power in many countries. Renewable electricity generation moves in the opposite direction, and increased 3% in the first quarter. This is partly due to the commissioning of new capacity in 2019 and partly because renewable power with low marginal costs is the last to stop producing when demand drops. Electricity from renewable sources is the only one to experience growth in 2020 despite the pandemic, albeit to a lesser extent than was predicted before the virus outbreak[24]. In Europe, this trend is developing faster than in other parts of the world. For the European power mix, renewable production increased by 11%, while fossil power production fell by 18% in the first half of 2020. This led to a 23% reduction in CO_2 emissions from the power sector, largely due to COVID-19, stable carbon prices and lower power demand[25]. Thus, the shift from fossil to renewable energy in the power sector continues. Another observation is that the stock values of renewable energy companies have remained relatively stable during the COVID-19 pandemic, while values in the oil and gas sector have fallen significantly compared with the S&P 500 Index. A similar trend is also emerging for companies that score highly on sustainability and social responsibility criteria [26].

-8%

Coal power has fallen by 8% during the COVID-19 pandemic

MORE

Renewable power production is gradually increasing

LESS

Fossil power production is gradually decreasing

1

THE FINANCIAL MARKET AS A DRIVER FOR THE ENERGY TRANSITION

In January this year, BlackRock – the world's largest asset management company – declared that sustainability is the company's new standard for investments[27]. As a result, BlackRock will withdraw from companies with a high exposure to coal. BlackRock is not alone in its belief that sustainability is an important investment criterion. About 25% of all investment funds in the United States are now based on various requirements for sustainable investments. The same trend is also being seen in the rest of the world, and so-called ESG investments in particular have had a sharp upswing*.

Sustainability was previously mainly regarded as adding costs to the companies, but there has been a fundamental shift in recent years towards sustainability increasing the value of companies. Values can increase in three main areas in particular: attracting and retaining a competent and motivated workforce, be preferred by the increasing number of more conscious customers, and the companies will face less climate risk than other comparable companies.

With the increased focus on green and sustainable investments, there is progress in developing various classification systems, including ISO standards.

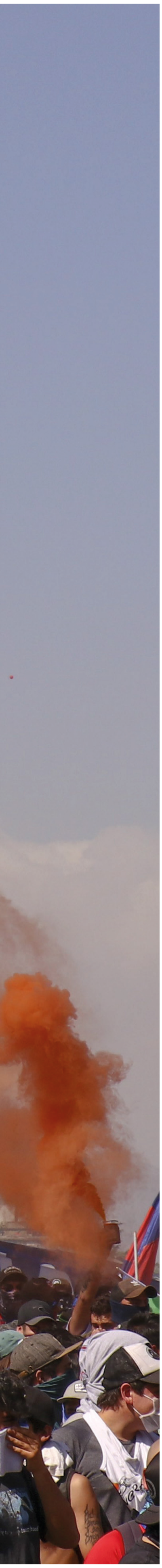
In April this year, the EU adopted a taxonomy regulation for sustainable finance, which sets specific criteria for each technology and defines what constitutes a sustainable investment. The regulation also imposes requirements for how greenhouse gas emissions and climate footprints are to be measured and reported.

The classification system is part of the EU's action plan on financing sustainable growth, which was launched in 2018. In order to classify an investment as sustainable, it must make a significant contribution to at least one of six environmental objectives without significantly weakening any of the others. Already from 2021, the financial industry and listed companies in Europe must report what percentage of their funds, portfolios or investments are sustainable in accordance with the classification system. The taxonomy will affect future investments in Europe in several ways, e.g. it is expected that a significant part of the EU's recovery package after the COVID-19 pandemic will be distributed to parties who make sustainable investments in accordance with the classification. It is likely that the taxonomy will increasingly be used as a condition for EU loans and support schemes, as well as for Member State schemes. A uniform taxonomy also makes it easier for customers and stakeholders to set requirements and choose the more sustainable investors. The EU's new classification system is thus expected to be an important driver for shifting more capital to green and climate-friendly technologies in Europe and thereby accelerate the transition to climate neutrality in 2050. How important the taxonomy will be in financing the green transition remains to be seen[28].

* ESG = Environmental, Social and Governance

CHILE

Protestors took to the streets in Santiago, Chile following a price hike in public transport.



Aiming for a just energy transition: different starting points

The energy transition is also about people. The last years, we have seen several examples of local opposition to specific climate measures such as increased petrol prices, road toll charges, public transport policies and new renewable power plant build-outs. Focus on a just energy transition can minimise the negative impacts and maximise positive opportunities of the transition and thereby increase public support.

The climate crisis is global, but the transition in the energy sector must largely take place at a regional and local level. Solutions and priorities will vary between countries and regions, and both international and regional cooperation will facilitate the transition. According to a benchmark ranking by the World Economic Forum, Sweden, Switzerland and Norway are ranked to be the countries most ready for the energy transition in the world. The Energy Transition Index measures the countries' current energy systems, as well as the framework and performance parameters for an efficient transition to a sustainable and cost-effective energy system.

In general, economies that are subject to greater competition are less fossil fuel dependent, have a stable regulatory framework and a strong political commitment are in a better position to cope with the transition to a low-emission society. Many developing economies are able to move directly to renewable and clean technologies and thus avoid fossil technology lock-in[29].

Fair distribution of responsibilities between countries have been important in the international climate negotiations, where special consideration is given to vulnerable and the least developed countries. At national and local level, it is crucial that the distribution of both costs and benefits of the transition is perceived to be as equitable as possible. This applies across regions, sectors, market players and socio-economic groups.

Visible examples of conflicts of interest related to specific climate measures in recent years have among others been related to the 'yellow vest' protesters in France, onshore wind construction and road tolls in Norway and the uproar over public transport in Chile. The energy transition will bring with it new opportunities as well as disadvantages for the population. In order to retain sufficient public support, the specific climate measures should not hit some groups disproportionately and they should be perceived as cost-efficient to minimise the overall transition costs. Climate policy is expanding into people's everyday lives more and more. The need for an equitable transition is becoming increasingly clear. The distribution of burdens and the sense of injustice must be taken seriously and handled carefully if the world is to manage a rapid enough transition to a low-emission society.

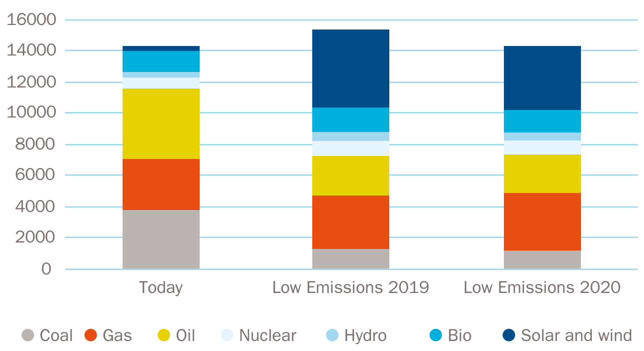
Whether support for the energy transition is weakened or strengthened by the COVID-19 pandemic remains to be seen. In general, people will be less able and willing in a prolonged recession to absorb new costs or burdens brought about by a transition. In the first instance, governments are keen to stabilise the economy in the short term. Many countries in Europe already have a large national debt and poor public finances, and the pandemic has exacerbated these problems. However, the use of green recovery packages may accelerate the pace of change. As mentioned above, the EU, France and Germany have adopted recovery packages with a green profile. Germany will spend EUR 8 billion to support the uptake of electric cars, EUR 9 billion on financing its hydrogen strategy and EUR 2 billion on energy-efficient buildings. France will spend EUR 8 billion to support the uptake of electric cars and will accelerate the roll-out of charging stations[30]. However, even though the EU and some countries are giving clear signals that green growth is a priority, countries around the world continue to subsidise fossil fuels. To date, the G20 countries have used 47% of COVID-19 energy recovery funds on fossil support, while 37% has gone towards clean energy, according to a survey conducted by the energy policy tracker[31].

2

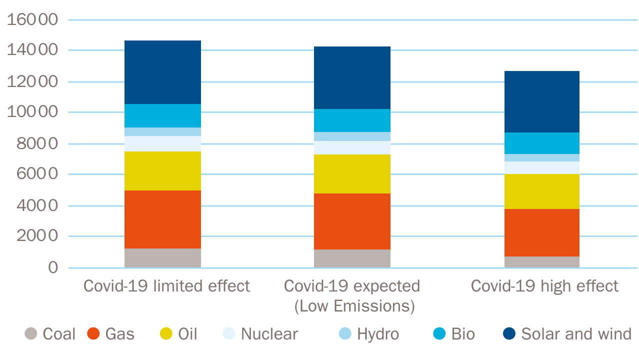
THE LOW EMISSIONS SCENARIO: A RENEWABLE AND ELECTRIC WORLD

THE LOW EMISSIONS SCENARIO: A RENEWABLE AND ELECTRIC WORLD

4 Global demand for primary energy today and in 2050 in the Low Emissions Scenario (Mtoe)



5 Global demand for primary energy in 2050 with various long-term effects of the COVID-19 epidemic (Mtoe)



Statkraft's Low Emissions Scenario is an optimistic but realistic scenario for a global energy transition from today to 2050. The scenario assumes that policy, markets and technology will in general move in the same direction. This chapter examines how renewable energy, electrification and emission-free hydrogen reduce greenhouse gas emissions, level out the need for energy and reduce the demand for coal, oil and gas up to 2050.

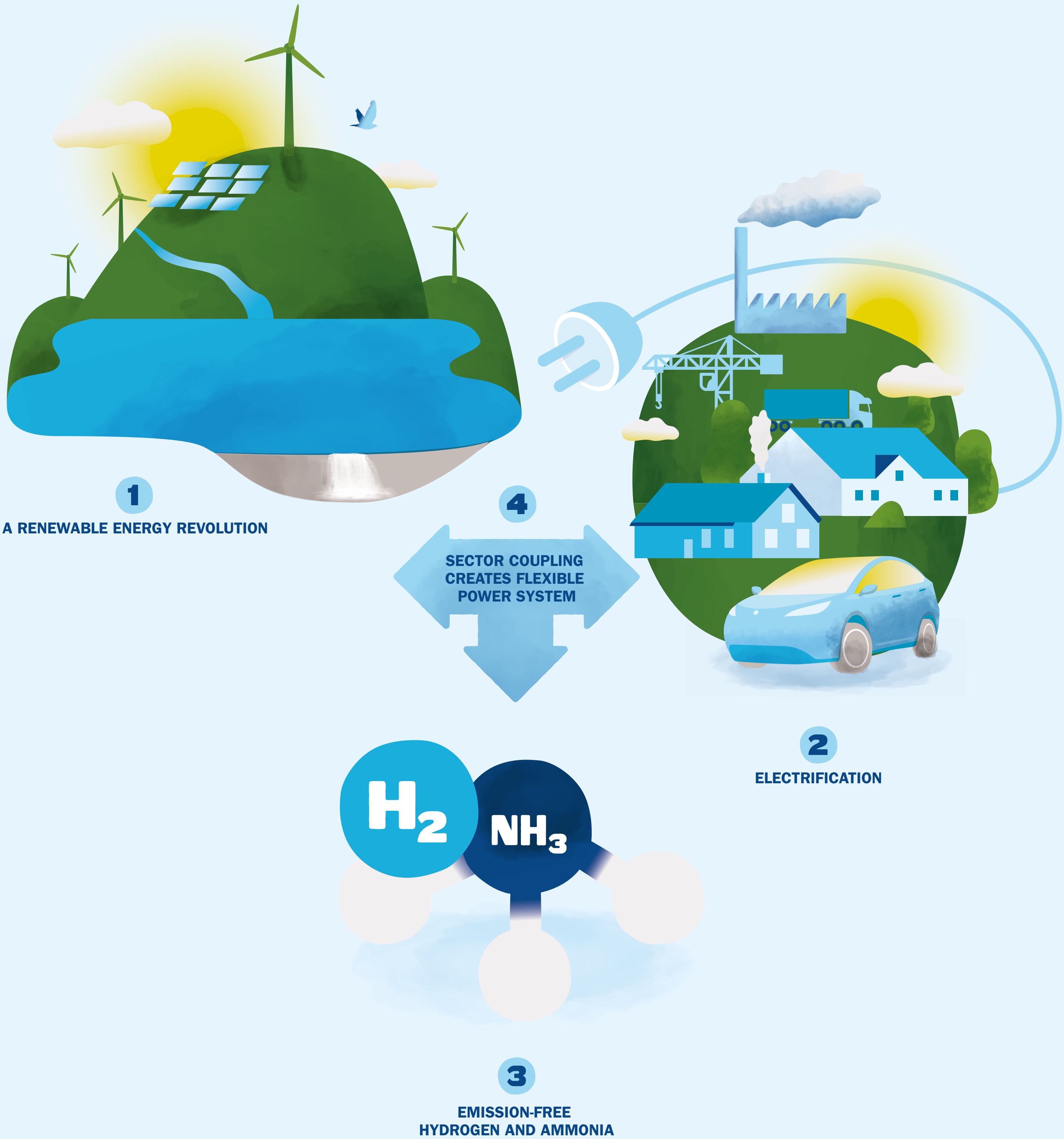
Driven by renewable power, the global energy world is becoming increasingly greener. However, the COVID-19 pandemic will lead to an economic recession in most countries in the world this year, and it will impact the economic growth and living standards globally for several years to come. In the Low Emissions Scenario, we have assumed that the global economy will be impacted for several years following the pandemic, while the focus on solving the climate crisis will continue. Although the growth rate in the economy will recover, the global economy and demand for energy are expected to remain lower over the entire period compared to expectations before the COVID-19 pandemic. The drop in energy consumption is expected to hit hardest in transport, industry and commercial buildings in 2020, but the effects of the pandemic will gradually be alleviated in the period up to 2050.

Energy efficiency improvements and electrification will gradually become more widespread, resulting in a further decoupling in the demand for primary energy and economic growth. The demand for primary energy in the Low Emissions Scenario will end at the same level in 2050 as today (Figure 4)*.

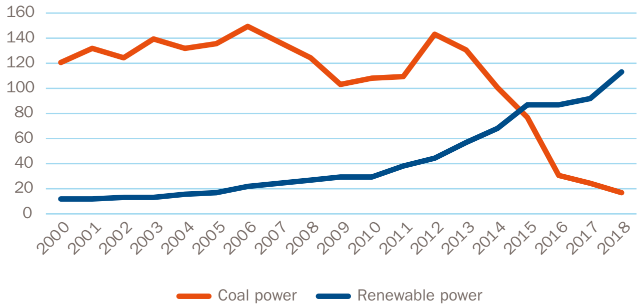
How long the economic crisis will last and the long-term effect on the demand for energy is highly uncertain at this point. If the economic crisis is relatively short-lived, the effect of the pandemic on the demand for energy up to 2050 may be minimal. In such an event, it is expected that the vaccination programme would be rolled out quickly and that the world would return to a 'new normal', very similar to before the coronavirus ('COVID-19 limited effect'). As mentioned above, the Low Emissions Scenario assumes that the effect on the demand for energy will be significant in the next few years, but this will diminish over time ('COVID-19 expected'). It is also possible that the economic crisis will be deeper and more protracted, with structural changes such as reduced trade and less global cooperation than is assumed in the Low Emissions Scenario. If this happens, the demand for primary energy would decline significantly over the entire period ('COVID-19 major effect') (Figure 5).

*The Low Emissions Scenario uses the IEA's calculation method. In primary energy calculations, zero losses are therefore assumed for renewable energy. With an alternative method that assumes approximately the same loss for fossil and renewable power production (38%), fossil fuels will cover around 30% of the primary energy in 2050 instead of almost 50%. However, the absolute amount of fossil fuels will remain unchanged regardless of calculation method (see information box 6 for more details).

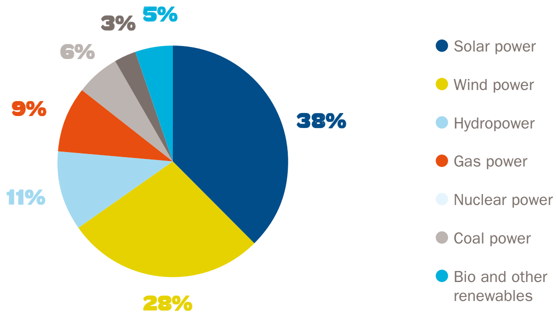
6 The Low Emissions Scenario is based on four important main trends that reinforce each other and create a powerful dynamic.



7 Historic power production in the UK from 2000 to 2018 (TWh per year)



8 Power supply sources as a share of global power production in 2050 (% of TWh)



The Low Emissions Scenario is based on four main trends that reinforce each other – these are presented in more detail later in this chapter (Figure 6) .

1 First, we are in the middle of a *renewable energy revolution:* falling costs for renewable power are pushing up renewable volumes, which is leading to further cost reductions

2 The second trend we are seeing is that this fall in costs, together with falling battery costs, is making it increasingly attractive to reduce emissions through direct *electrification* of transport, buildings and industry

3 Third, the cost reduction for renewable energy, together with electrolysis, will make decarbonisation through the utilisation of *green hydrogen and ammonia* attractive to areas that are difficult to electrify directly

4 Fourth, increased *interaction between the energy sectors* via smart solutions will give the power system more flexibility, and thereby enable a higher share of variable renewable power.

Put together, these four trends will result in *lower greenhouse gas emissions,* a flattening of energy demand and a fall in the demand for coal, oil and gas.

In order to gain enough momentum in this dynamic, policy must primarily facilitate, rather than hinder, the interaction between markets and technology. The cost reduction for clean technologies will in turn make it easier for politicians to increase their climate ambitions and facilitate a transition in line with or faster than the Low Emissions Scenario. The strong mutual interdependence between countries and regions via global value chains has intensified considerably in recent years. We now observe opposite trends. Many countries and businesses have experienced how global and complex value chains can make them more vulnerable to unforeseen situations. The need for secure supply and efficiency can incentivise them to move production closer to the end use despite the potentially higher costs. In the Low Emissions Scenario, we assume increased focus on regional value chains, but with a continued significant global dependency and global trade in goods and services facilitating the energy transition.

A renewable energy revolution: solar and wind power are outcompeting coal and gas power

The costs of building new renewable power plants are steadily falling compared with fossil power. The costs of new solar and wind power will eventually fall to the point that they outcompete coal and gas power plants that have already been built. This is fostering a strong momentum throughout the world. Fossil fuels are being outcompeted by renewable energy.

Several of the largest power systems in the world are being decarbonised, and this can happen very quickly. Norway is in a special position, with a virtually emission-free power system. In the UK, coal accounted for 30-40% of the power supply just ten years ago, but today the coal share is just 2% (Figure 7). At the same time, we have seen a rapid increase in renewable power generation[32]. The UK set a record in June this year with two full months without any coal power generation, partly due to COVID-19 and record-low gas prices. This is the first time since the Industrial Revolution[33]. Similar trends have also been observed in the United States and the EU. In the United States, coal power generation fell by 16% in 2019. The corresponding reduction in the EU was 24%, followed by a drop of 32% in the first half of 2020[34].

The changes in the energy systems are being driven by rapidly falling costs for solar and wind power. It is already cheaper in most parts of the world to install renewable power production when building new capacity. Solar and wind power will also increasingly outcompete coal and gas power plants that have already been built (Figure 9). It will therefore be cheaper to build new renewable capacity than run existing fossil power plants. This is creating a strong momentum around the world, where fossil fuels are being outcompeted by renewable energy. The world is in the middle of a renewable energy revolution.

In the Low Emissions Scenario:

2.5%

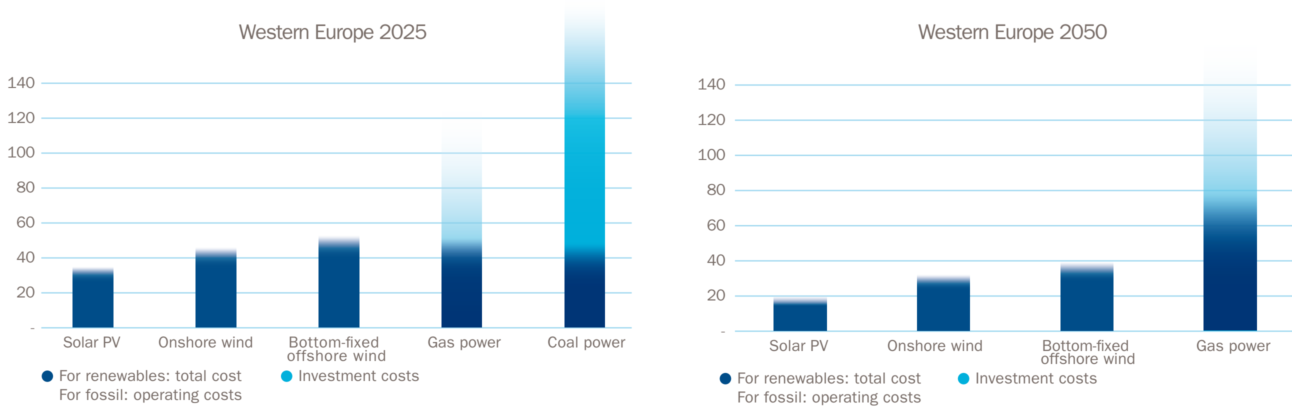
The demand for electricity will grow by an average of 2.5% per year over the period

Passenger cars, city buses, vans and two- and three-wheelers will be electrified quickly

-70%

We envisage more than a 70% reduction in battery costs by 2050

9 Average life cycle costs for various power-producing technologies in 2025 (left) and 2050 (right) for Western Europe (EUR/MWh)



In the Low Emissions Scenario, the capacity in the global power sector will increase three-fold between now and 2050. This entire increase, and more, will be covered by renewable energy (GW). Solar power generation will increase by 12% per year on average from today, while wind power generation will increase by more than 8% per year. Unlike solar and wind power, hydropower has undergone industrialisation over the last hundred years, and is the largest source of renewable energy today, with installed capacity of 1,290 GW globally.

Large hydropower plants are already operating at a high efficiency (over 90%), and there is no expectation of the same cost reduction as seen for solar and wind power. Hydropower is expected to grow over the period at a slower pace, 1.5% per year on average*.

As in last year's analysis, solar power generation will surpass wind power, hydropower, coal power and gas power, and will be the largest source of power from around 2035. This is primarily due to the low costs, but also because solar PV plants are flexible in terms of location and are relatively fast and easy to build compared to other technologies.

Hydropower production will surpass coal power in 2040 and gas power five years later. In 2050, renewable energy will constitute more than 80% of the global power generation, and 66% of this will be generated from variable sources such as solar and wind power (Figures 8 and 12).

The largest coal producing and consuming countries in the world, such as China, India and Indonesia, are in a special position. Coal is an integral part of society in these countries and local coal prices are often regulated and significantly lower than global coal prices. Clear political commitment is therefore required in these countries, particularly over the next few years, to drive the transition at the pace assumed in the Low Emissions Scenario. For more details on the challenges related to the coal phase-out, see information box 2.

Growing demand for flexibility in the world's power systems: a high share of solar power changes the price profiles over days and seasons

An ever-increasing share of variable power production is changing the global power sector as it exists today. While power generation has traditionally been flexible, with coal, gas, and in some places, hydropower, it will gradually be more at the mercy of solar and wind resources. The high share of variable solar and wind power requires greater flexibility in the power system.

Statkraft's analyses show that the power markets can handle the high share of variable, renewable power production applied in the Low Emissions Scenario**. There are multiple solutions. Within *power generation*, greater flexibility is being built into existing and new power plants, and power technologies with complementary production profiles are being developed. Increased flexibility in hydropower (where available) will be one of the most economically attractive alternatives for meeting long-term flexibility needs. Hydropower becomes more flexible by changing production profiles in the short and long term in order to adapt to the demand in the power system. It is also very often cost-optimal to expand *both* solar and wind power in power systems with a high share of variable renewable power, even though one of these technologies has the best resources in the area. This is due to the fact that the production profiles differ because the wind often blows at a time that complements the solar radiation. This complementarity can take place within a day or over longer periods and seasons. In addition to increased flexibility in power generation, we expect several flexibility solutions in *demand, grids* and *storage* to enter the market. We will return to the various solutions in the section on sector coupling and in information box 3 on hybrid projects later in this chapter.

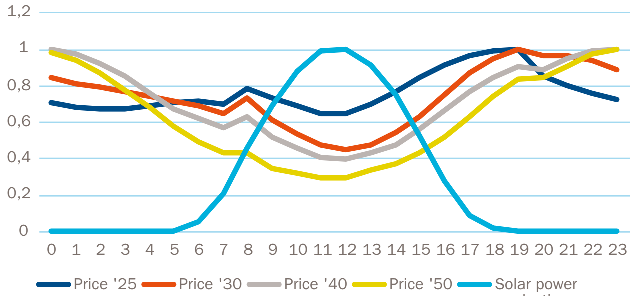
The various flexibility solutions will reduce price fluctuations by boosting low power prices and curb high prices. Depending on how much flexibility is built into the power system, a significant change is still expected in the daily and seasonal wholesale power price profiles globally up to 2050. This is primarily due to the large amount of solar PV in the power systems globally (Figures 10 and 11).

It is not possible at this point to predict the optimal composition of the various flexibility solutions in the future. It is therefore crucial that these solutions can compete in the market on equal terms.

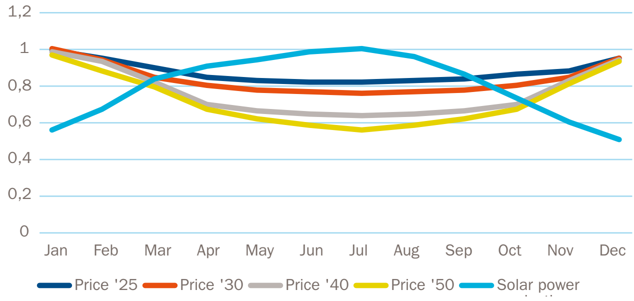
*Flexible hydropower is well suited to mountain areas where reservoirs can be established in existing lakes, nearby steep slopes and with solid rocks. The number of locations that can offer this combination is limited.

**Statkraft models power markets in detail, hour by hour, for the Nordic countries, Europe, India and countries in South America up to 2050.

10 **The daily power price profile increases** with higher share of solar power production in the power system (illustration). The power price is shown for the years 2025, 2030, 2040 and 2050, and solar power production is shown per GW.



11 **The seasonal power price profile increases** with higher share of solar power production in the power system (illustration). The power price is shown for the years 2025, 2030, 2040 and 2050, and solar power production is shown per GW.



The actual demand for flexibility and the value of flexibility are determined in real time. This value must therefore be visible to both the consumer and the producer. A fixed retail power price per day, for example, will not motivate consumers to move their electricity consumption by charging their electric car or heating their hot water tank during the night when typically the total power demand tends to be lower.[35].

Solar PV: the technology is evolving and the utilisation rate is increasing

Substantial growth is expected in solar PV capacity globally. The Low Emissions Scenario estimates that the capacity will be 24 times greater in 2050 than it is today (14,100 GW in 2050). Before the pandemic, both China and Europe were in an exciting transition away from subsidised installations, and this growth may pick up again in the near future.

The cost reductions over the period will be driven by a maturing of the market and the gradual development of solar PV technology. Solar PV with tracking and bifacial panels (which produce power from both sides of the panel) are largely used to maximise power production from solar power plants. Bifacial solar PV panels get an extra efficiency boost from sunlight reflection on the reverse side. This type of solar PV panel covered about 4% of the installed capacity in 2019. Tracking is used to adjust the solar PV panels according to the position of the sun, which enables more direct sunlight to hit the panels. Installation and operating costs are higher for trackers, but they increase the utilisation rate of the solar PV. This technology is becoming more common as costs fall, and is already standard in sunny regions.

For solar PV plants, the life cycle costs will largely depend on the underlying solar resource. However, we are also seeing major local variations. Land rent, property tax, capital costs, local labour costs and auction conditions are factors that determine the profitability of the individual projects. The large volume increase in the Low Emissions Scenario may also entail additional costs for balancing the power system. In such an event, hybrid projects may be a partial solution (information box 3). The advantage of solar PV is that they are very flexible and can be installed on roofs, on lakes, along roadsides and on agricultural land. The latter may become crucial for protecting rather than competing with food production, and for minimising resistance.

Floating solar power plants on lakes, canals and dams is a relatively new technology. This technology has a large potential in areas with restrictions on land use, difficult ground conditions, or where there is a need to limit evaporation from the water. Solar PV modules are mounted on top of floaters that are anchored to the seabed. This technology differs from onshore solar PV in that it is designed to withstand movements in bad weather and in waves and currents, and is made from materials that can withstand high levels of humidity. Floating solar power plants on hydropower reservoirs can be built at a reduced cost because a grid connection already exists.

2

TRANSITIONING AWAY FROM COAL POWER PRODUCTION IS A CHALLENGE FOR THE MAJOR COAL COUNTRIES

Coal currently covers 27% of the primary energy mix and 38% of the global power demand. Coal is mainly used in the power and industry sector. In Statkraft's Low Emissions Scenario, global demand for coal will fall by an average of 3% per year, and by more than 5% per year in the power sector between now and 2050. In 2050, coal power will account for 3% of the global power production. This is a major transition away from coal. However, the big coal producing and consuming countries in Asia will still have a significant proportion of coal left in their power mix, especially India and China.

Commercial and political drivers in some regions could delay the transition and decelerate the coal power phase-out. This is one of the biggest barriers to a transition in line with the Low Emissions Scenario. Most of the remaining coal nations have large national coal reserves where the entire value chain represents jobs. The coal industry is partly concentrated in areas with limited activity in other sectors, making the transition a major challenge. Consideration for the coal industry and fear of social and political unrest are key reasons in some countries for not phasing out coal power. The use of own coal reserves also safeguards national energy independence, which can be even more important during a period with high global tensions. The large degree of monopoly and regulated power sectors in many of these countries can reduce the competitiveness for renewable energy sources. This can also coincide with a political desire to maintain a national coal industry[36].

China and India are the largest coal consumers and producers in the world, and accounted for 50% and 13% of global coal demand in 2018 respectively.

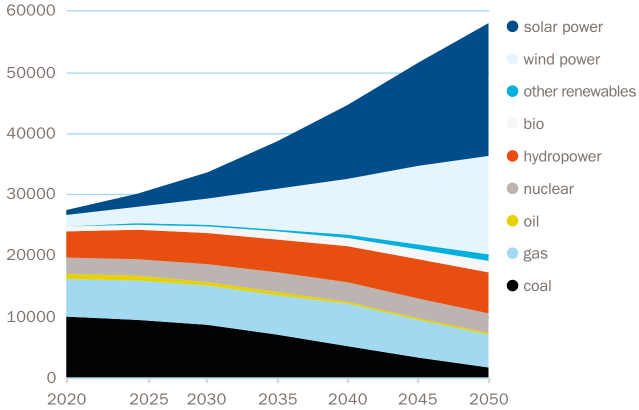
In 2019, 17 countries opened new coal power plants. The average age of the global coal fleet is just 18 years. The lifetime of a coal power plant is around 40 years, which means that in countries with cheaper domestic coal, the power plants built in the last ten years can potentially continue to run for the next 30 years if they are not disincentivised by carbon pricing or regulations. China has a stated ambition of being carbon neutral by 2060, and will launch its next five-year plan from 2021 this year. Here, the coal phase-out will be an important issue. The idea of raising the capacity cap for coal power to 1,300 GW has been discussed, which could result in new expansion in China corresponding to the entire coal fleet in the United States[37]. Chinese companies are also active in the development of new coal power beyond its country's borders. Large state-owned companies depend on exports of coal-related goods and services. State-owned companies are used for the design, construction, insurance and financing of coal power projects abroad – normally for the same project. This creates closer relations with the recipient countries.

The nation, the business sector and the labour market thus have a lot to loose in the major coal countries in the event of a rapid phase-out of the coal industry[38]. Clear national and international political ambitions and support is therefore needed for the transition*.

*For an analysis of a delayed coal phase-out in Europe, see the next chapter.

Solar panels on agricultural land

12 Power production globally from today to 2050 (TWh) in the Low Emissions Scenario



Wind power: standardisation and turbine size are driving the development

The global wind power capacity is expected to be seven times greater in 2050 than today. This makes wind power the second largest power technology, with 4,700 GW of installed capacity in 2050.

Wind power will account for almost 30% of the global power generation in 2050. Compared to the solar PV industry, the supply chains in the wind power sector are more regionally based today, especially for offshore wind. This trend is expected to continue throughout the period and has only intensified due to the COVID-19 pandemic. Cost reductions are mainly being driven by strong competition and standardisation of the most important components. The increasing size of turbines is also an important factor in cost reductions. After 2030, 8 MW wind turbines, standing at a height of more than 200 metres, are expected to be standard for onshore installations. Although no radical technological breakthroughs in onshore wind power are expected during the period, there will be a number of improvements in design, operation and maintenance. Digitisation, the use of artificial intelligence and optimisation algorithms will become more important, along with energy management. This will help to optimise production with regard to power prices, variable costs and service life. Opposition to new onshore wind projects has been increasing in recent years in several countries. This highlights the importance of clear, transparent approval processes with local involvement (see Chapter 3 for more details).

The life cycle costs for wind power projects vary considerably by location, and are impacted by the underlying wind resource, the distance to the power grid, construction costs and capital costs, as well as local labour costs and the local supplier industry. As wind power becomes increasingly exposed to the power market, the profitability of projects will be more dependent on auction conditions, commercial terms and underlying power prices. The design of wind farms and operating strategies will play a greater role in the optimisation of production.

The expansion of offshore wind globally is estimated to be moderate compared to onshore wind. This is primarily due to the fact that the costs for onshore wind are generally expected to be lower than for offshore wind. Nevertheless, bottom-fixed offshore wind in countries with good offshore wind resources will soon be able to compete with onshore wind. This is currently seen in the United Kingdom. Restrictions on land areas can also make offshore wind an interesting prospect, especially if the extra cost compared to onshore wind is small. Offshore wind has in general a greater energy potential than onshore wind power, and is less subject to conflicts over land. We therefore expect the share of offshore wind power to increase up to 2050. Hydrogen production from the relatively large volumes of power generated by offshore wind can also represent a relevant opportunity for some countries.

Floating offshore wind is still dominated by pilot projects and is still far more expensive than bottom-fixed offshore wind. In markets where it is possible to build bottom-fixed offshore wind power plants, it is therefore expected that this technology will be considered first. Consequently, floating offshore wind power plants will primarily be relevant in areas where the potential for bottom-fixed offshore wind and other renewable technologies is limited. This is particularly relevant in countries such as Japan, South Korea and parts of the United States, where most of the sea area is unsuitable for fixed installations, either due to depth or seabed conditions. In the longer term, the lack of suitable areas for bottom-fixed offshore wind may also become a factor in parts of Europe. Developments in the coming decades will largely depend on industrial and climate policy goals in different countries and whether this technology is subsidised to such an extent that costs can come down to a competitive level. There is therefore a great deal of uncertainty around how much capacity will be realised and what cost level will be achieved.

X24

Solar power capacity will be 24 times greater in 2050 than today, and wind power capacity will be seven times greater

-5%

The annual demand for coal in the power sector will fall by more than 5% on average from today to 2050

Renewable power and batteries reduce emissions through electrification

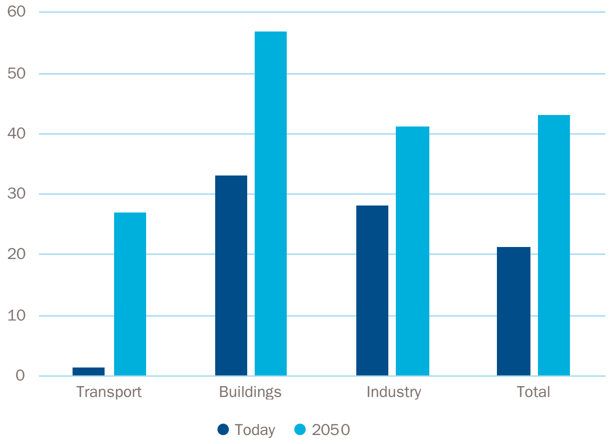
In the Low Emissions Scenario, electricity will cover 43% of the global energy demand in 2050, compared to around one-fifth today. In this section, we will look at how transport, buildings and industry can decarbonise by utilising the emission-free energy from wind and solar power through electrification.

The ever-decreasing costs of solar and wind power mean that electrification will be the most cost-effective climate measure in many cases. If the world is to succeed in cutting emissions, electrification in sectors such as transport, buildings and industry will be crucial.


WE ARE IN THE MIDDLE OF A RENEWABLE ENERGY REVOLUTION


FOR A
RENEWABLE
WORLD

13 Electrification as a percentage of final energy per sector in the Low Emissions Scenario



In the Low Emissions Scenario, the demand for electricity doubles over the period, growing by an average of 2.5% per year. Renewable electricity will account for the entire growth in electricity demand, and will in addition push coal, gas and oil out of the power mix. The share of fossil fuels in the power mix will decline from the current 64% to 13% in 2050.

The share of electricity in the *transport sector* will grow the most in the Low Emissions Scenario, ending at 27% in 2050, from a very low starting point of 1%. Oil accounts for over 90% of energy consumption today.

Rapid cost declines are being observed for batteries - driven by increasing numbers of electric vehicles. In the Low Emissions Scenario, passenger cars, city buses, vans and two- and three-wheelers will be electrified quickly. Our analyses show that the life cycle costs for these electric vehicles are rapidly becoming lower than for fossil fuel vehicles in a growing number of countries. In the Low Emissions Scenario, we envisage more than a 70% reduction in battery costs by 2050. Efforts are currently underway to increase the battery production capacity and diversify the supply chain. The market is not mature and production line improvements still represent a large potential. If a 70% cost reduction is to be achieved, battery production will also be dependent on other chemical compounds than those being used today. This will improve battery efficiency, reduce material costs and in addition help prevent a shortage of components and materials.

Stationary batteries account for around 12% of total battery capacity in 2050 (GWh), while the rest of the volume is from the transport sector. The Low Emissions Scenario estimates that almost all new lighter vehicles worldwide will be battery-powered, while almost 60% of new heavier vehicles will run on battery or hydrogen in 2050 (Figure 14).

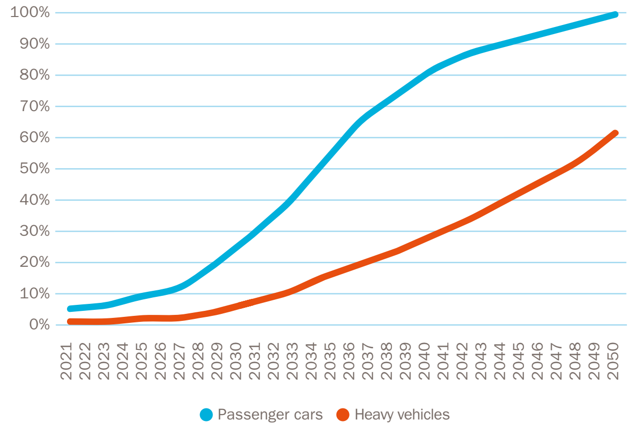
3 HYBRID PROJECTS AS COMPETITIVE ALTERNATIVES: SOLAR, WIND AND HYDROPOWER WITH BATTERY OR GREEN HYDROGEN

In a power system with an increasing share of variable renewable power production, we recognise that combining different technologies at the same site may be a practical solution. This is known as a hybrid project. By combining variable renewable power production with storage solutions such as batteries or green hydrogen, such projects can independently handle fluctuations in power prices and add both energy and flexibility to the system.

Co-location of batteries and/or electrolysers with solar, hydro and/or wind power can save installation and grid connection costs. With increasing volumes of solar or wind power in the power systems, power prices will fall during periods with a lot of sun or wind, typically in the middle of the day (see Figure 10). When, for example, solar PV and batteries are co-located, periods with low or negative power prices can rather be used to charge the batteries. The batteries can send this power to the grid when the demand for power increases and the supply otherwise falls. In many countries in the world, this will be throughout the afternoon.

With falling costs in renewable energy, batteries and green hydrogen, we expect various types of hybrid projects to increase in number. The profitability of a hybrid project may be better than for the individual sub-projects. Hybrid projects can also provide critical system services to local grid operators and be particularly relevant in areas with limited grid capacity.

14 Battery-electric and hydrogen-electric share of new car sales globally in the Low Emissions Scenario (%)



Energy efficiencies in buildings and appliances, direct electrification in the form of heat pumps, as well as hydrogen and bioenergy, will push down emissions from *energy use in buildings* by 46% over the period. The share of electricity of the total final energy demand in the Low Emissions Scenario will increase from 33% today to 57% in 2050.

Within *energy use in industry,* the cement industry, chemicals industry and steel industry account for 12-14% of global CO_2 emissions today[39]. Direct electrification will be the most cost-effective climate solution for low-temperature heating processes in these industries. A closer interaction between the industry and buildings sector is also expected. For example, industry will be able to add surplus heat into the district heating system that supplies heat to buildings, and receive cooling in return. Data centres, for instance, have a constant need for cooling and produce a lot of heat that would otherwise be wasted. Heat pumps could exploit the temperature difference and increase the supplied heating and cooling by means of electricity. In the Low Emissions Scenario, we expect the share of electricity in industry to increase from 28% to 41% globally over the period (Figure 13).

Renewable hydrogen and ammonia are attractive climate solutions where direct electrification is challenging

Emission-free hydrogen is emerging as an attractive climate solution in areas where direct electrification is difficult. Several countries have increased their focus on the role of hydrogen in the past year, and the EU launched its own hydrogen strategy in 2020.

Decarbonisation via direct electricity is not suitable or economically feasible in some sectors and applications. Examples would be the transport of heavy loads over large distances, high-temperature heating processes and chemical processes in industry. In such cases, a combination of emission-free hydrogen, bioenergy, carbon capture with utilisation/storage, energy efficiency improvements and circular economy will reduce greenhouse gas emissions. The competitiveness of these solutions varies between the applications and will largely depend on carbon prices and policy instruments. However, as the cost of renewable electricity falls, hydrogen from electrolysis is expected to become more and more competitive compared to the fossil alternatives in these areas.

4 ELECTRIFICATION IN PARALLEL WITH A HIGHER SHARE OF RENEWABLE ENERGY IN THE POWER MIX WILL REDUCE EMISSIONS

If we are to succeed in limiting global warming, we do not have much time. To maintain the pace required in the Low Emissions Scenario, countries need to switch from fossil fuels to electricity in parallel with the decarbonisation of the power sector. According to our analyses and external research, with the current European power mix, electric cars will already be emitting less than half the amount of greenhouse gases as a diesel car in a life cycle perspective. With a clean power sector such as in the Nordic region and France, emissions are reduced by more than 80% with an electric car compared to a diesel car. This is because the electric engine is so efficient that almost all the energy goes to propulsion, while in fossil engines more than two-thirds of the energy is lost. The power mix in Europe and in the world is rapidly becoming greener as more solar and wind power is added. This increases the positive climate effect of switching from fossil to electric cars.

The same logic also applies to heating from electric heat pumps instead of gas. Heat pumps can produce three to four times more heat than traditional boilers with the same energy consumption. Our analyses show that even a heat pump using electricity from 100% coal power will account for less or the same amount of greenhouse gas emissions as a highly efficient gas boiler operating at 90% efficiency. This does not include methane leaks from the gas distribution network.

In Europe, the power sector is regulated by the European Emissions Trading Scheme (ETS), where there is a cap on the allowances available. Increased demand for electricity from transport and buildings thus leads to emissions being shifted from the sectors that are not subject to emission allowances to a sector that is. This means that electric cars and electric heat pumps shift greenhouse gas emissions into the EU-capped emissions trading sectors while reducing emissions at the same time. If increased electrification creates a need for more power capacity, new solar and wind power will be the most economically feasible alternatives for new power production (Figure 9).

Electrification in parallel with the development of an increasingly greener power sector thus becomes a socio-economically attractive option and a necessity for achieving the climate targets.

Hydrogen can be transported and used across sectors and applications, stored for long periods, used in chemical reactions, e.g. in the petrochemical and ammonia industry, and is emission-free when used. Thus, hydrogen has a number of properties that complement the use of direct electricity. Hydrogen produced from renewable electricity and water (referred to as 'green hydrogen') is emission-free both in production and in utilisation, while hydrogen produced from fossil fuels with carbon capture and storage can be around 90% emission-free (referred to as 'blue hydrogen').

Today, around 117 million tonnes of hydrogen is already being produced, primarily from natural gases and coal. Hydrogen is currently used in industry and accounts for over 2% of energy-related CO_2 emissions globally. In the Low Emissions Scenario, industry will have to reduce its emissions and more of today's fossil-based hydrogen will be produced emission-free. As part of the EU's new industrial strategy, the European Commission proposes to use the innovation fund from the emissions trading system to stimulate emission reductions in energy-intensive industry[40]. One of the ambitions is to achieve zero emissions in the steel industry. The steel industry currently accounts for around 22% of industrial CO_2 emissions in the EU. It may be possible to use hydrogen instead of coal as a reducing agent for all iron and steel production, as well as for some of the heating processes[41].

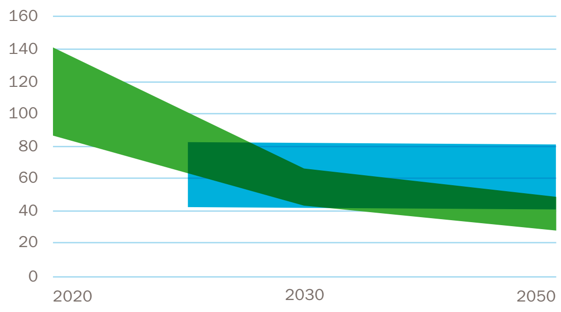
Within heavier vehicles, the Low Emissions Scenario estimates that electric vehicles, powered by either hydrogen fuel cells or batteries, will dominate in 2050. An analysis of life cycle costs shows that both electric and hydrogen-powered trucks will be competitive compared to diesel trucks from the end of the 2020s. Hydrogen and battery-electric trucks will complement each other for different applications depending on driving distance, load and utilisation time. Natural gas, energy efficiency, hybrid trucks, and blending of biofuels and synthetic fuels will have a role to play in the transition towards zero-emission trucks.

Over the past year, several countries have accelerated their focus on hydrogen, and Germany, Norway and the EU, among others, launched their own hydrogen strategies in 2020[42]. The EU has outlined a plan to scale up a European hydrogen industry where at least 6 GW of renewable hydrogen electrolysis should be in place by 2024, at least 40 GW of renewable hydrogen electrolysis by 2030 and large-scale use of renewable hydrogen technology in the steel and chemical industries, among others, by 2050.

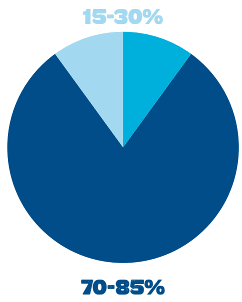
CELSA AND STATKRAFT signed an agreement with the intent to develop a complete value chain for green hydrogen in steel production.


P Automat
P

15 Cost developments for green and blue hydrogen in the Low Emissions Scenario (EUR/MWh)*



16 Costs for green hydrogen in 2050 by cost component (%)



The German strategy states that hydrogen from renewable energy will be the long-term sustainable solution, while emission-free hydrogen from, for example, fossil gas (blue), will be relevant for Germany during a transitional period. They expect it to be possible for countries to trade emission-free hydrogen. In the Low Emissions Scenario, emission-free hydrogen will cover 6% of the total final energy demand in the world by 2050.

Cost developments for hydrogen from renewable energy

Green hydrogen from renewable electricity is already assumed to be competitive with blue hydrogen in areas with good renewable resources. In the last five years, the costs for electrolysers have fallen by more than 30% and are expected to fall further as their use increases (Figure 15).

Green hydrogen is currently 50%-100% more expensive than hydrogen from fossil energy without carbon capture. Blue and green hydrogen are believed to complement each other rather than being in competition with one another. Blue hydrogen will mainly be produced on a large scale and centrally, while green hydrogen is typically produced on a smaller scale, often locally, close to demand.

Due to its low volumetric energy density, both the transport and storage of hydrogen will be challenging and costly. Existing salt caverns are assumed to be suitable for large-scale hydrogen storage. Rebuilding and upgrading pipelines may be an alternative for transporting large volumes of hydrogen. As they stand today, most natural gas pipelines are not compatible with a high volume of hydrogen and significant investment is required in infrastructure. Our analyses show that it will generally be attractive to produce hydrogen from renewable energy close to demand where renewable resources are available.

Cost reductions in renewable energy and electrolysers will enable green hydrogen to compete with fossil hydrogen in several applications as early as 2030. The power price is an important cost parameter and could account for typically 70-85% of the costs in 2050 (Figure 16). Newer models of electrolysers are designed to be flexible and efficient, and can therefore provide flexibility by shifting power demand to periods with high levels of solar or wind power production**.

Sector coupling through electrification creates flexibility in the power system

Sector coupling in its broadest sense relates to how all the sectors with high energy consumption are linked more closely with the power sector. This means that the power sector is becoming an increasingly central part of the energy system.

The energy from the power sector will to an increasing extent be used in buildings, industry and transport, either through direct electrification, or through the use of hydrogen/ammonia as energy carriers. The demand for power from the buildings, industry and transport sectors will be far more flexible in the future than the demand traditionally seen in the power market, and sector coupling will therefore completely change the dynamics in the power sector.

Sector coupling using smart charging solutions could provide highly needed short-term flexibility in the power system. Passenger cars are parked for around 95% of their lifetime. This also applies to electric cars. There are now over 7 million electric cars in the world, and sales increased by 6% in 2019. Even during the COVID-19 crisis, car manufacturers are continuing to focus on electric cars. Volvo has set a goal that electric cars will account for 50% of new car sales in 2025, and believes that the COVID-19 crisis will only accelerate the electrification trend[43]. Total investments in electric car manufacturing in the EU were 19 times higher in 2019 than in 2018, reaching around EUR 60 billion. Germany accounted for two-thirds of the investments, of which 20% went to the manufacturing of car batteries. For example, Volkswagen will increase its electric car production in Europe fivefold in two years, to 745,000 electric cars in 2021, and will have 75 different electric car models on the roads from 2029[44]. In the Low Emissions Scenario, there will be more than 1.4 billion electric cars on the roads in the world by 2050. This corresponds to around 19,000 GWh of battery storage capacity, depending on factors such as self-driving and mileage. The battery storage capacity in electric cars will thus constitute an attractive source of flexibility for the power system with the help of smart charging solutions.

Smart charging can move a significant part of the power demand from the transport sector to times of the day with high solar and wind power consumption and/or little other consumption. It will also eventually be economically feasible for batteries to return electricity to the

* IHS and Statkraft analyses. 100MW PEM electrolyser 72% efficiency. EUR/MWh. Blue hydrogen costs are uncertain, and depend on the cost of transporting and storing carbon.

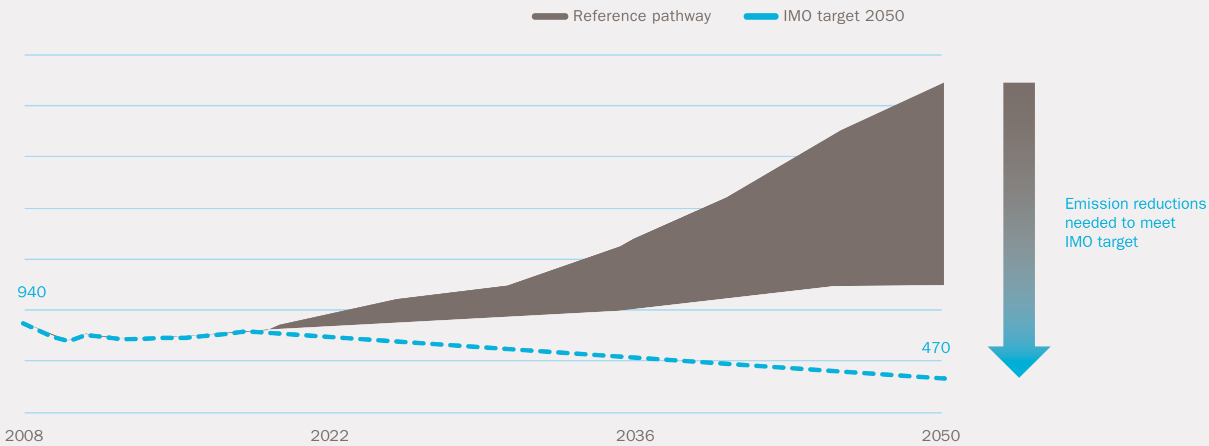
** Today, there are mainly two electrolysis technologies in use: polymer-electrolyte membrane (PEM) and alkaline electrolysis.

5

DECARBONISING SHIPPING WITH GREEN AMMONIA

The maritime sector faces major challenges in reaching the target to halve greenhouse gas emissions by 2050 relative to the 2008 level as agreed in the International Maritime Organization (IMO). Emissions from international shipping constitute 2-3% of global CO_2 emissions.

17 Emission reductions needed in shipping to meet the IMO climate target in 2050 (Mt CO_2e per year).

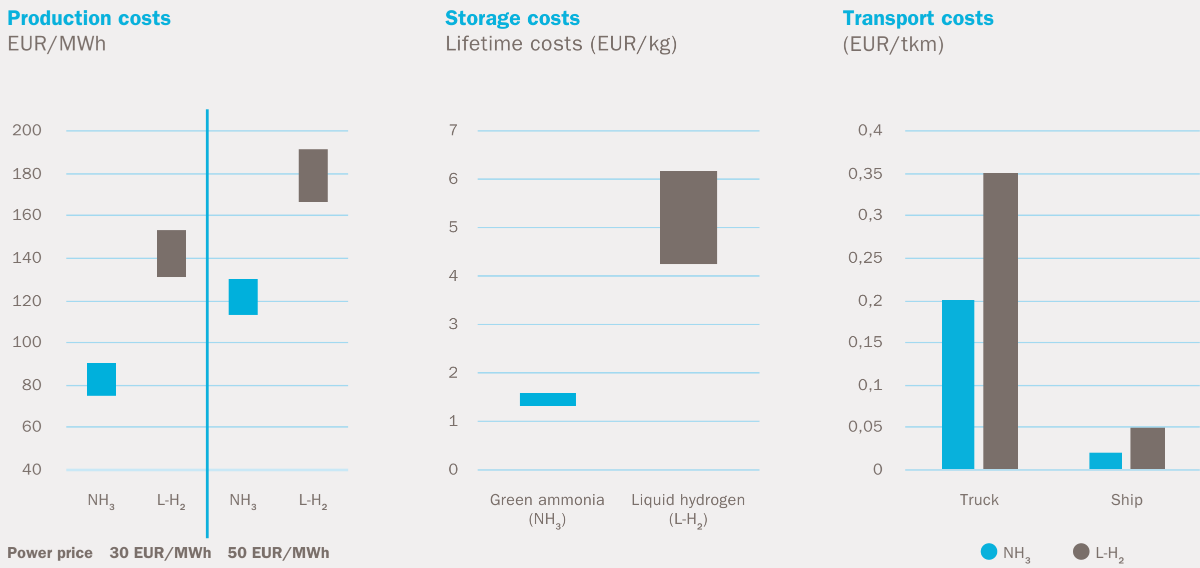


Today's marine heavy fuel oil is cheap and has a high energy density, therefore alternative low- and zero-carbon fuels are not expected to be competitive without carbon pricing and policy incentives. Most carbon-neutral fuels meet challenges in terms of volume and weight limitations. Fully battery electric ships are best suited for short, predictable journeys, such as ferries or riverboats. Storage space for compressed hydrogen will present a challenge for longer distances. Liquid hydrogen is a possibility, but is expected to be less attractive than renewable (green) ammonia. This is primarily because ships running on liquid hydrogen will be more costly and because ammonia has a better volumetric energy density than liquid hydrogen. Ammonia is a hydrogen carrier that is easier to store and distribute than liquid hydrogen (Figure 18).

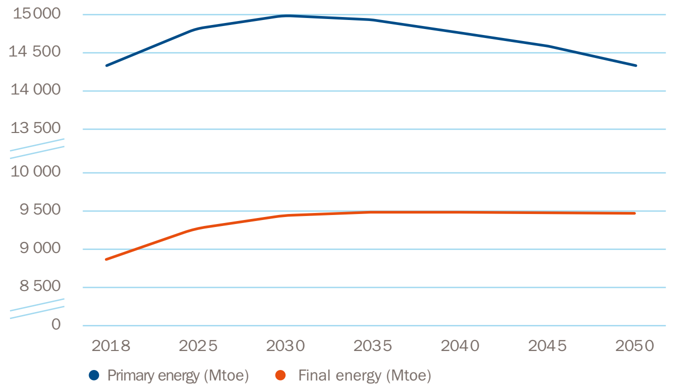
Green ammonia is emerging in many areas as one of the best carbon-neutral fuels for long distance shipping. Green ammonia does not emit greenhouse gases either in production or use, and can be used as a fuel or as feedstock in the fertiliser industry. Production converts nitrogen and renewable hydrogen in a Haber-Bosch process into ammonia (NH_3). Combustion of ammonia in an internal combustion engine produces NO_x emissions that must be handled with a catalyst similar to the technology in current diesel engines. Green ammonia can also be used directly in a fuel cell. In fuel cells, no NO_x is created, and the efficiency is greater than in internal combustion engines. This is expected to be the most attractive option in many applications in the long term. Ammonia can also be converted back to hydrogen, but energy loss and costs make this a less attractive option than hydrogen produced locally, in most cases. The cost of green ammonia is expected to fall as costs come down for renewable power and equipment such as electrolysers and Haber-Bosch plants.

Today, around 150 million tonnes of fossil ammonia is produced annually and is used in fertiliser production and other chemical industrial processes. Ammonia is transported by ship and therefore an established infrastructure already exists. Ammonia is toxic, and safety regulations are required for handling. There are no carbon-neutral fuels commercially available for the maritime industry today. With a lifetime of around 30 years for ships, the uncertainty surrounding future alternative fuels is a major challenge for the industry.

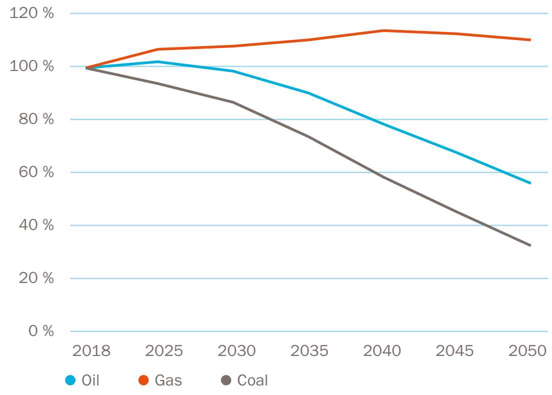
18 Costs for production, storage and transport of liquid hydrogen (L-H_2) and green ammonia (NH_3).



19 Demand for primary energy and final energy from today to 2050 (Mtoe). The need for primary energy will end at the same level as today in 2050 (blue line), while final energy will increase from the current level (red line).



20 Fossil fuel demand indexed to 2018.



grid. Smarter and more flexible demand, such as smart charging, presents a viable opportunity to introduce much higher shares of renewables into the overall power generation mix. It reduces demand in periods with little wind and sun, and increases demand in periods with a lot of wind and sun, thereby reducing the need for forced curtailment. By reducing peak demand, the overall costs associated with grid expansion can also be lowered.

Additional peak demand from electric car charging can otherwise lead to a significant need for upgrades and investments in the power grid. Using smart charging systems can reduce the investment needs in the distribution grid for the uptake of electric vehicles of between 40% to 90%, depending on the region and characteristics of the power grid according to IRENA[45].

Sector coupling via the electrification of buildings provides similar benefits to the power systems. Smart heating of water and buildings entails parts of the heat demand being moved to periods with high renewable power production or little other consumption, and associated lower power prices. The need for heating has a seasonal profile that follows temperature changes in the region. In general, the need for heating is therefore greater in winter than in summer in the Northern Hemisphere. Our analyses show that by introducing a smarter electricity-to-heating solution in Europe, where more of the demand is moved to periods with highly variable power production within a day, greenhouse gas emissions from the buildings sector are reduced by 1% to 2% over the period. The need for battery storage in the power system will also be reduced by 5%*.

Smart charging of electric cars and smart heating of buildings will be crucial for short-term flexibility. These can offer flexibility within 24 hours, but will not solve the need to move power over longer periods of time (long-term flexibility) when there is little wind and sun over several days. Renewable, flexible hydropower will be able to cover the need for such long-term flexibility. Few countries have this option, but over time, *sector coupling via emission-free hydrogen* will also enable long-term flexibility. Hydrogen produced from renewable energy at low (or negative) power prices, can be an attractive and flexible decarbonisation solution to be used in the transport, industry and buildings sector. In addition, emission-free hydrogen could be converted back to power and provide flexibility to the power system, and take on the same flexibility role that natural gas has today. Due to efficiency losses from power to hydrogen and back to power, this will be a relatively expensive flexibility solution. Hydrogen to power can be supplied either in gas turbines (CCGT, OCGT) or fuel cells. With an efficiency of just over 50%, almost half of the energy will be lost in the process if the heat is not utilised. When fuel cells combine power and heat, it is possible to achieve around 90% efficiency, where around 50% can go to power and around 40% to heat recovery. It is already possible to blend around 20% hydrogen into existing gas power plants without upgrading. This can reduce emissions somewhat (5-7%), but will also increase costs and reduce the efficiency of the power plant. The power plants need to be further upgraded if there is to be further blending.

MORE demand flexibility. Smart heating of water and buildings and smart charging solutions will move parts of the power demand to periods with high renewable power production or little other consumption

The Low Emissions Scenario follows a two-degree pathway

Even with continued population and economic growth globally, the Low Emissions Scenario follows a two-degree pathway. The demand for coal will peak before 2025, before declining. For oil, the peak will occur around 2030, and for fossil gas around 2040.

Today, the world is still dependent on fossil energy sources, and the increasing population and economic growth continues to push up the need for energy. Fossil energy is used today to produce power and heat, to transport people and goods, and in various industrial processes. In Statkraft's Low Emissions Scenario, demand for primary energy will continue to increase until the 2030s, gradually slowing before levelling off and declining towards 2050. This will happen even with continued growth in the population and economy. The energy intensity in the economy will decline, and the need for primary energy will end up at the same level in 2050 as today. Final energy demand will however still increase by 7% over the period in the Low Emissions Scenario. This shows that less energy is lost in the conversion processes from primary to final energy in 2050 compared to what is the case today (Figure 19 and information box 6). Fossil energy will be replaced by renewable energy and the fossil fuel share in primary energy will fall from 81% today to 52% in 2050**.

*Analysis assumptions: High heat demand and high renewable power production were moved closer to each other within a day and correspondingly for periods with low heat demand and low power production. This evens out the power production and demand profile throughout the day.

**Primary energy is the amount of energy extracted before energy loss as a result of conversion, transformation and distribution to end users (see information box 6 for more details).

6

PRIMARY ENERGY: DIFFERING COUNTING METHODS FOR FOSSIL AND RENEWABLE ENERGY MAKE A DIFFERENCE

A common objection to the energy transition is that 80% of the world's energy needs currently stem from fossil energy sources, and that only 4% is from renewable sources (measured in primary energy). Phasing out fossil fuels using renewable energy when the difference is so overwhelming can look like an impossible task.

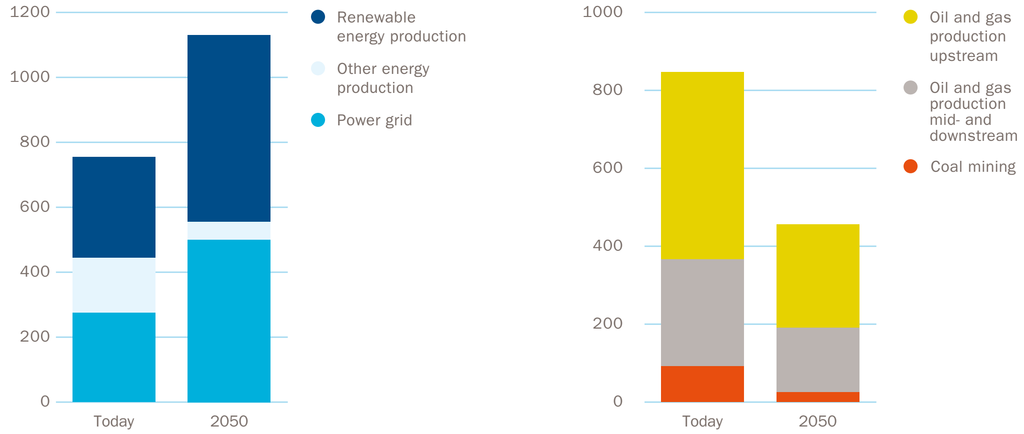
Primary energy is defined as a form of energy that exists in nature, but which has not been subject to human processes of conversion, for example in a power plant or a car. All energy in the energy source that can theoretically be utilised is included in the statistics. This means that fossil energy sources are normally quantified based on the theoretical latent energy, while renewable energy is quantified based on the electricity generated.

This sounds like a technical difference, but has an important implication: A modern coal power plant has an efficiency of 40%, which means that 60% of the latent energy in coal (the 'primary energy') is lost in the conversion from coal to electricity. In the statistics, a transition from coal to renewable electricity will result in 60% lower energy needs without the actual end use of electricity having changed. The loss in the use of fossil energy consists of heat that is emitted to the surroundings.

This means that for every unit of renewable electricity used to replace modern coal power, coal consumption will decrease by 2.5 units. For every unit of renewable electricity used to run an electric car that replaces fossil fuel engines, oil consumption will decrease by around 4 units. Today, coal converted to electricity accounts for about 17% of the world's primary energy supply, while the renewables share is about 4%. Since one unit of renewable energy can replace more than 2.5 units of coal, we do not need to increase the renewable volumes fivefold to replace *all* coal power. We 'only' need to increase renewable volumes by around 70%. Oil used for transport currently accounts for about 21% of the world's energy supply. If we increase the global renewable production by 50%, this could in theory cover all oil used in transport if all transport was able to switch to direct electricity.

There is currently a wide gap between fossil fuels and renewable energy, and phasing out fossil fuels presents a major challenge. Nevertheless, it is worth noting that this problem is not so extensive as it often is portrayed.

21 Investments in the power sector (graph to the left) and fossil energy (graph to the right) in USD billion per year from today to 2050 (USD 2020)



In the Low Emissions Scenario, all the fossil energy sources are affected by the energy transition, but at different times.

Coal will be affected first and to the greatest extent. In the Low Emissions Scenario, demand for coal already reaches its peak before 2025 and is followed by a structural decline in demand up to 2050. The coal share of primary energy will end at 9% in 2050. The peak in demand for *oil* will be around five years after that for coal, and the demand for *natural gas* will subsequently peak around 2040. Demand for natural gas will increase by 0.3% per year on average from today, but will start to decline after 2040. Natural gas will still have a role to play in the buildings, transport and industry sectors, and in balancing power systems, especially during longer periods with little wind and sun. In the Low Emissions Scenario, demand for coal and oil will fall by 68% and 44% respectively, while demand for gas will increase by 10% from today (Figure 20).

Investments in the power system will be more than twice as high as investments in fossil energy in the Low Emissions Scenario in 2050 (Figure 21). The trend we have seen in recent years will continue, with investments shifting from fossil energy to the power sector and renewable electricity (Figures 2 and 3). It is also worth noting that the total investment level in the energy system in 2050 will be at approximately the same level as today, despite economic and population growth. This is partly due to a decoupling between energy demand and economic growth and partly due to falling technology costs for renewable energy.

In the Low Emissions Scenario, declining demand for all fossil fuels towards 2050 will reduce global energy-related CO_2 emissions by 47% between now and 2050, ending at 17.6 Gt CO_2 in 2050. The power sector accounts for the largest share of energy-related CO_2 emissions today, and will experience the greatest emission reductions over the period, with 70%. Power sector emissions will gradually decline as coal power and subsequently gas power are replaced with renewable power. The industry sector is the second largest emitting sector today and the share will increase over the period. The transport sector now mainly uses oil as an energy source and is the third largest emitting sector. Emissions from both transport and buildings will fall by around 50% over the period, while emissions from the industry sector will fall by a quarter.

This means that the energy-related CO_2 emissions in the Low Emissions Scenario are in line with the IPCC's two-degree pathway, but the decline in emissions is still not fast or steep enough to be in line with a 1.5-degree pathway (Figure 22)*. The biggest difference between the Low Emissions Scenario and a 1.5-degree pathway is speed – we envisage the same solutions, but a 1.5-degree pathway will require much faster action, with several technological solutions being developed in parallel.

-44%

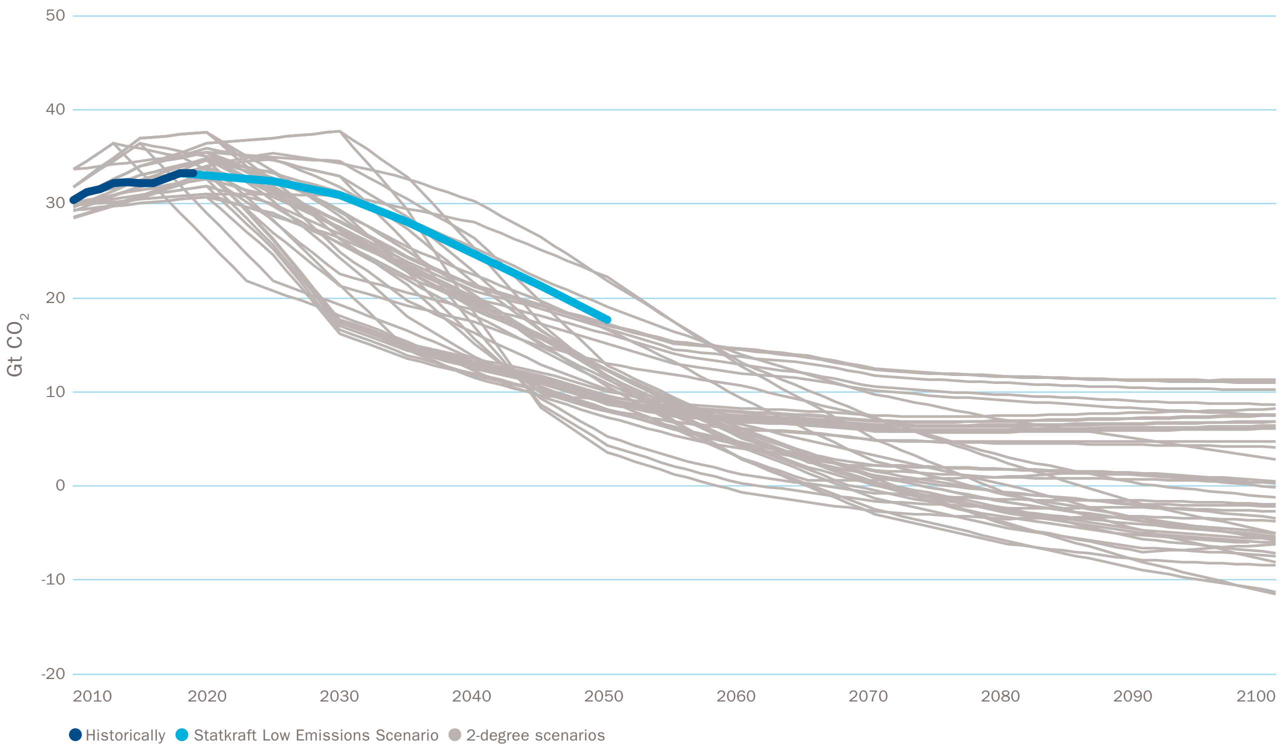
Demand for oil is declining by 44% over the period

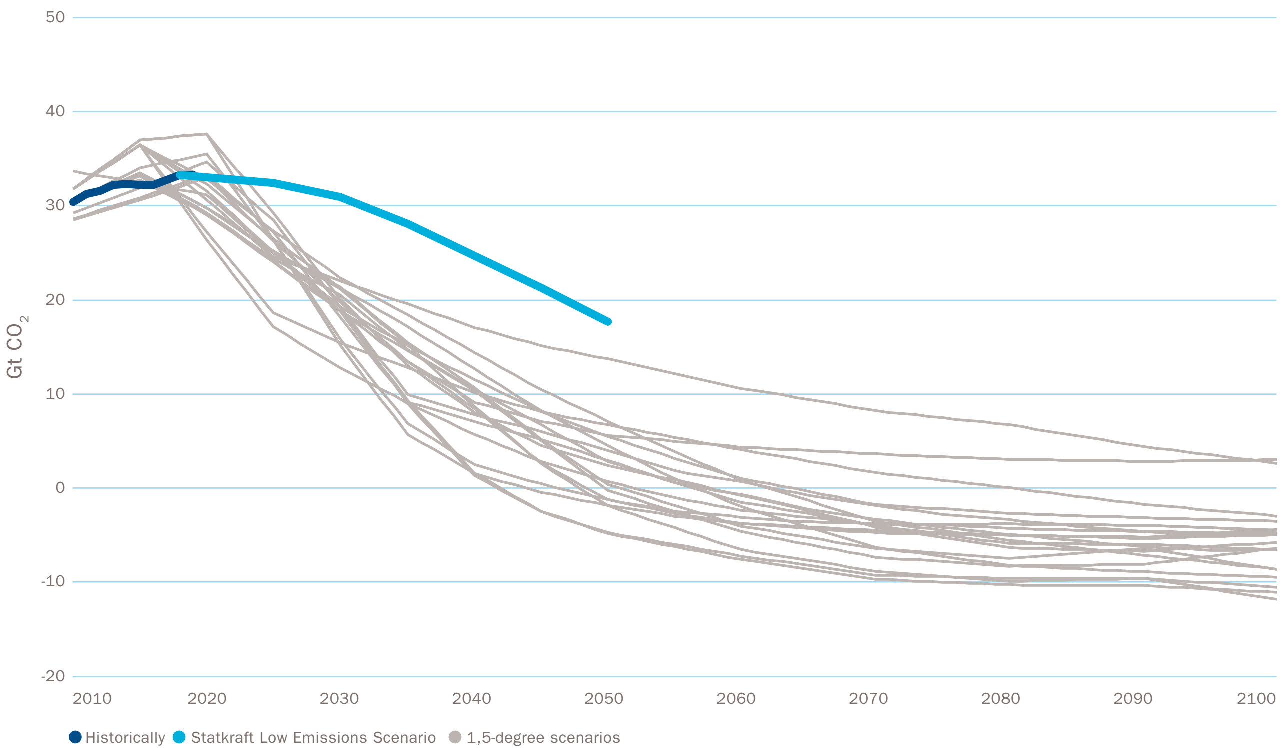
17.6 GT

Global energy-related CO_2 emissions will fall by 47% over the period, ending at 17.6 GtCO_2 in 2050, in line with a two-degree pathway

*The IPCC's two-degree and 1.5-degree pathways have been developed using various Integrated Assessment Models (IAMs), which apply different assumptions for technological and socioeconomic parameters.

22 Annual energy-related CO_2 emissions in Statkraft's Low Emissions Scenario compared with other two-degree scenarios (top) and 1.5-degree scenarios (bottom). Includes emissions from fossil sources and bioenergy with carbon capture and storage.[46, *]





*The graphs above have been prepared by Glen Peters, Research Director, CICERO, and retrieved from IAMC 1.5°C Scenario Explorer and Statkraft's analyses[46].

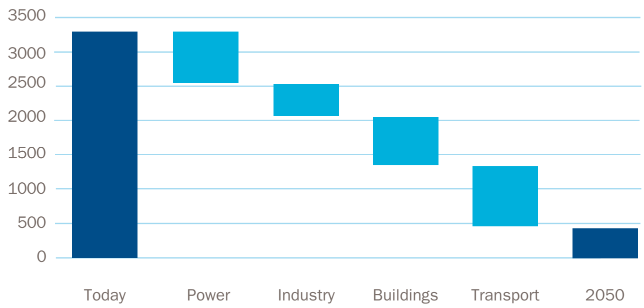
3

WHAT CAN DECELERATE OR ACCELERATE THE TRANSITION?

BERRY BURN WIND FARM, in the Scottish Highlands

WHAT CAN DECELERATE OR ACCELERATE THE TRANSITION?

23 Emission reductions in Europe in the Low Emissions Scenario from today to 2050 per sector (energy-related CO_2 emissions in Mt).



Statkraft's Low Emissions Scenario assumes that policy, markets and technology will in general move in the same direction. If this does not turn out to be the case, the global energy transition may become less efficient, more expensive and slower. In this chapter, we look at enablers and barriers that could arise in the European energy transition up to 2050, and what consequences this might have. Examples are: Political climate ambitions, different uses of carbon pricing, restrictions on electrification in transport and heating, delayed coal power phase-out, and increased opposition to the build-out of onshore wind power.

An important assumption in the Low Emissions Scenario is that there is political will to decarbonise society in a cost-efficient manner. Since the United States withdrew from the Paris Agreement, the EU has assumed greater leadership in maintaining the momentum in global climate politics. The EU sets ambitious climate targets and shows a willingness to implement policies and regulations so the targets can be reached. In recent years, emissions from the power sector have seen a rapid fall in Europe. However, if the EU is to achieve its long-term climate targets, cuts must also be made in sectors that are harder to abate and in areas that are closer to the consumers. Policy instruments will need to be strengthened in order to reduce emissions quickly enough in all sectors. This is reflected in the EU's new green growth strategy, which combines clear political climate ambitions with market-based solutions (the European Green Deal). The growth strategy highlights climate and sustainability as key components and establishes a clear social commitment to ensure an equitable transition.

However, other key trends could take European climate policy in a different direction. Support for populist parties has been growing in recent years. International cooperation is meeting resistance. The pandemic could conceivably lead to reduced support for climate measures and international cooperation. The climate tends to be deprioritised on the political agenda when other more immediate crises arise.

So far, the EU climate ambitions do not appear to have been weakened by COVID-19. The EU's recovery plan has a clear green profile and climate is still high on the EU agenda. Nevertheless, there is still uncertainty associated with how the climate ambition will be reached and the member states' implementation of the growth strategy. In parallel with this, we are also observing some strong local opposition to a number of specific climate measures.

In this chapter we have used a cost-optimised energy system model for Europe to gain greater insight and shed light on the consequences of the following enablers and barriers to the transition [47,*]:

- Climate ambitions up to 2050 – how will high, low and delayed climate ambitions impact the energy transition?
- Carbon pricing in Europe – what are the consequences of homogenous/differentiated carbon pricing across countries and sectors?
- Barriers to electrification – how will this affect the energy transition?
- Delayed coal power phase-out in Europe – what other solutions are relevant?
- Barriers to onshore wind power development – what are the alternatives?

*The analyses presented in this chapter have been conducted by Statkraft in collaboration with T. Burandt, K. Hainsch and K. Löffler (Technische Universität Berlin)[47]. The energy system model assumes that the most socio-economical solutions for Europe are chosen. Cost optimisation is applied across regions and sectors. In the analyses it is assumed that the EU succeeds in meeting its climate targets, even with additional barriers. This does not apply to the ones that look at alternative climate targets. The targets are therefore not achieved in the way we believe is most cost-efficient and is assumed in the Low Emissions Scenario.

7

THE LOW EMISSIONS SCENARIO IN EUROPE – A COST-EFFECTIVE TRANSITION

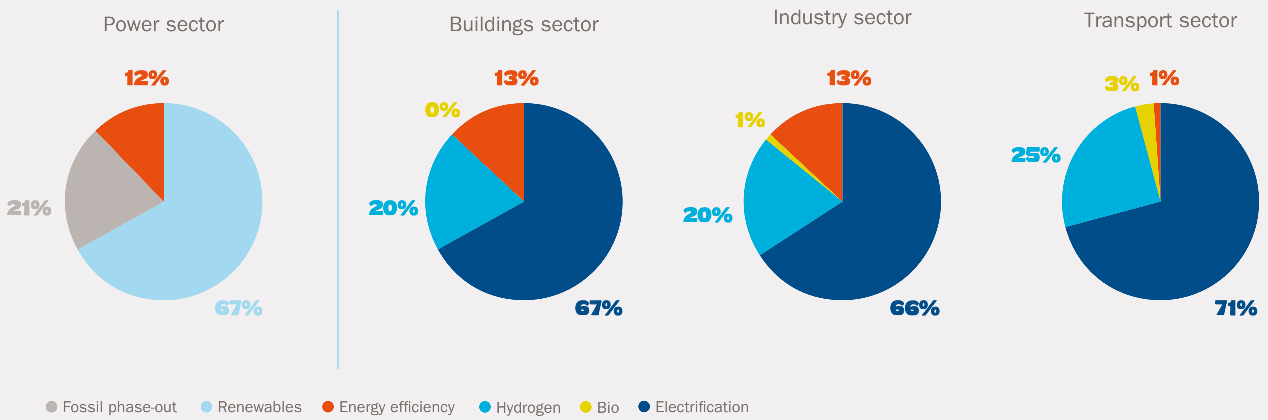
In the Low Emissions Scenario this year, we assume that energy use in the EU will be decarbonised according to a 90% climate target in 2050 in line with the European Green Deal ambitions. We expect COVID-19 to result in lower economic growth in Europe over the period, which in turn will reduce the need for energy and electricity to a greater extent than estimated before the pandemic.

A cost-effective transition to the Low Emissions Scenario in Europe will result in an almost fully decarbonised power sector in 2050, with 95% renewable power production, where more than 80% is from variable sources. Solar PV will account for half of the installed capacity in the power sector in 2050, with an annual capacity growth of approximately 8%. Wind power will account for just over a third of the capacity, and will see an annual growth of 6%. Meanwhile, the need for electricity will increase by around 60% from today. The transport and power sectors will account for the largest emission reductions between now and 2050 (Figure 23).

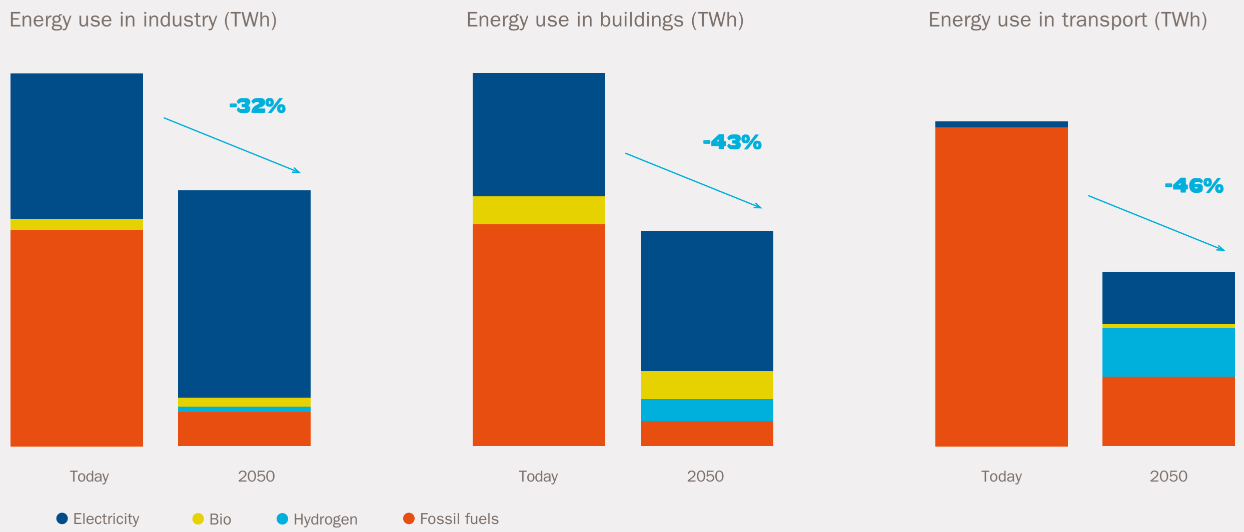
In the power sector, two-thirds of the emission reductions will stem from renewable sources, approximately one-fifth will be a result of phasing out coal power and the remainder will be due to energy efficiency improvements. In the other sectors, electrification will be the most cost-efficient climate measure across time, geography and sectors. In our analyses, electrification accounts for more than two-thirds of the emission reductions in the transport, industry and buildings sectors. Emission-free hydrogen accounts for a fifth of the emission reductions in the buildings and industry sectors and a quarter of the emission reductions in the transport sector over the period. Emission-free hydrogen as a climate solution will accelerate after 2030 and end with a 12% share of the total final energy in Europe in 2050. Energy efficiency improvements and bioenergy will account for the remainder of the emission reductions (Figure 24).

Although electricity demand will increase, the total final energy demand will fall by 46%, 43% and 32% for transport, buildings and industry respectively (Figure 25). This is due to energy efficiency, the replacement of fossil energy sources with electricity, and the fact that electricity in end use is generally more efficient than fossil energy in most applications. Fossil fuel demand in the buildings, industry and transport sectors will fall by a total of 83% between now and 2050 in our analyses.

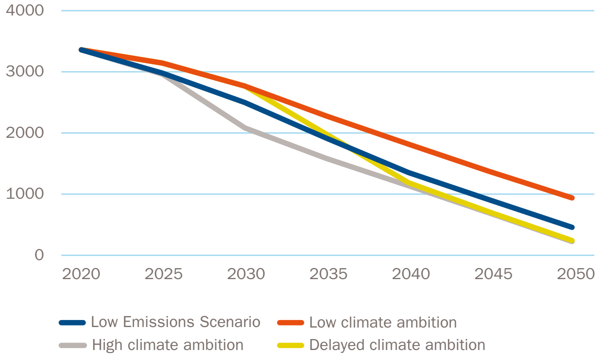
24 Cost-optimal decarbonisation per sector in Europe between now and 2050 in the Low Emissions Scenario. Industry does not include feedstocks.



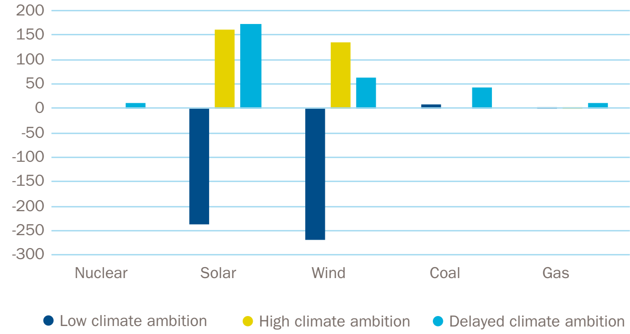
25 Final energy demand in the Low Emissions Scenario today and in 2050



26 Emission pathways in Europe with different climate ambitions (energy-related CO_2 emissions in Mt).



27 Changes in installed capacity (GW) in the power sector in Europe for different climate ambitions compared to the Low Emissions Scenario



High, low and delayed climate ambition towards 2050: unpredictability is costly

A delayed climate ambition will be very costly for Europe, first and foremost because it will lead to a larger build-out of coal, gas, solar and wind power. By 2050, total energy system costs in Europe will be 4% higher than in the Low Emissions Scenario.

The climate targets for Europe from 2030 to 2050 are still being negotiated. We have analysed the impact of various European climate ambitions on the energy transition, in comparison with the Low Emissions Scenario. Several recent studies estimate that to be consistent with a two-degree pathway and a 1.5-degree pathway, EU countries must cut their greenhouse gas emissions by 80% and 91–96% respectively in 2050 relative to 1990 levels[48]. The following emissions pathways were analysed:

- *Low climate ambition*: An energy transition in the EU that maintains the current 40% climate target in 2030 and 80% ambition in 2050
- *High climate ambition:* An energy transition in the EU that achieves a 55% climate target in 2030 and 95% in 2050
- *Delayed climate ambition:* A delayed energy transition in the EU where we assume that the climate target of 40% in 2030 remains, and after 2030 there is an agreement on increasing the ambition to reach a 95% target in 2050.

We have compared these three pathways with the Low Emissions Scenario, which assumes a 90% climate target in 2050.

The *Low climate ambition* for Europe will entail a slower transition and a European energy mix that is not in line with the EU's new growth strategy and ambition for climate neutrality in 2050. The renewable share in the power sector will, nevertheless, end up significantly higher than today, with as much as 93% in 2050, with 76% stemming from variable power (TWh). Electricity consumption will grow by around 40% from today, but will be significantly lower than in the Low Emissions Scenario as a lower climate ambition reduces the need for electrification. Solar and wind power capacity will continue to increase significantly from today, but at a slower pace. The installed capacity of solar and wind power in Europe will be 500 GW lower in 2050 than in the Low Emissions Scenario (Figure 27).

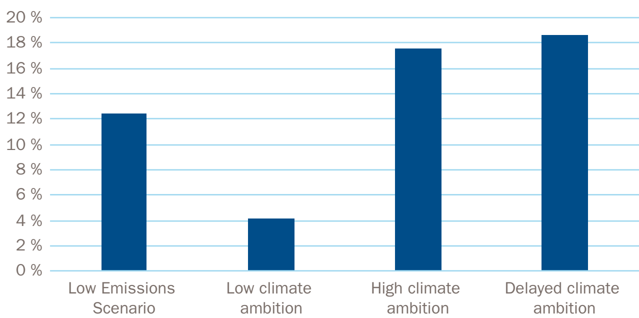
New solar and wind power production will cover the entire growth in electricity consumption between now and 2050, at the same time replacing 87% of all coal and gas power that is phased out in the power mix over the period. The power and transport sectors will account for the largest emission reductions from today (Figure 29). A low climate ambition will decelerate the transition in the transport sector, as well as buildings. Emission-free hydrogen will play a smaller role in 2050 compared to the Low Emissions Scenario. Hydrogen has a bigger role from 2040 onwards in all three pathways (Figure 28).

The *High climate ambition* in Europe will more or less give the opposite result. The climate targets of 55% and 95% are in this case expected to be set in the near future and the targets will be predictable for the market players over the period. The power sector will be completely decarbonised. The renewable power share will be 96% in 2050, and there will also be some nuclear power and biomass power plants with carbon capture and storage, resulting in negative emissions. In 2050, the transport sector will be left with more than 70% of the remaining emissions, as the last abatement options in the transport sector will be relatively more expensive. At the same time, the demand for power will increase by 70% from today. The solar and wind power capacity will grow significantly and we will end up with about 300 GW more solar and wind power than in the Low Emissions Scenario (Figure 27). Emission-free hydrogen will be an integrated part of the energy system towards the end of the period and demand will be significantly higher than in the Low Emissions Scenario (Figure 28). Most of the increase in hydrogen demand will be in the transport and buildings sectors.

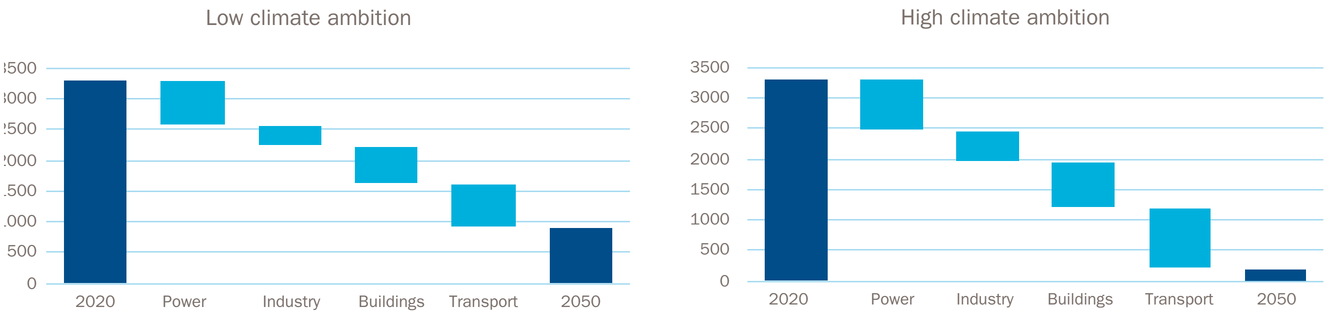
95%
renewable power in Europe in 2050 in the Low Emissions Scenario

12%
hydrogen share of final energy use in Europe in 2050 in the Low Emissions Scenario

28 Hydrogen share (%) of final energy for Europe with different climate ambitions in 2050.



29 Emissions reductions from 2020 to 2050 in the Low climate ambition case (left) and the High climate ambition case (right) (energy-related CO_2 emissions in Mt).



Our analyses show that the last few years of the transition will be particularly challenging in a *Delayed climate ambition,* where the EU countries only manage to realise higher climate ambitions after 2030 and end up with a 95% climate target in 2050. In this case, there will also be more coal and gas power plants in the system that eventually end up as stranded assets. This lack of predictability around long-term climate targets lead to unwise and delayed investments by market players and a less cost-optimal transition. This will result in a significantly more expensive transition for Europe as a whole. In our analyses, energy system costs will be 4% higher over the period compared to the Low Emissions Scenario*. The result will be a larger capacity growth of coal, gas, solar and wind power than in the Low Emissions Scenario (Figure 27). A delayed climate ambition will require energy-related CO2-emissions to be cut by an average of 12% per year compared with 8% in the Low Emissions Scenario for the period 2030-50. This illustrates the importance of acting early and setting predictable long-term climate targets to ensure that we end up with the most cost-effective decarbonisation pathway over time.

Overall, the analyses show that:

- A low climate ambition will lead to a slower transition, particularly in non-power sectors
- A high climate ambition will lead to more renewable power and emission-free hydrogen
- A delayed and unpredictable climate ambition will be costly for society.

Strengthened carbon pricing accelerates emission reductions

Throughout the decade, there has been a gradual increase in the use of carbon pricing worldwide. Twenty-two per cent of the world's greenhouse gas emissions are currently covered by carbon pricing. Our analyses show that the European transition will be quicker if higher climate ambitions are combined with carbon pricing.

One of the most important instruments for meeting the climate targets is setting *a price on carbon*. Gradually more countries and regions are introducing emissions trading schemes or carbon taxes[49]. By setting a price on greenhouse gas emissions, businesses will be incentivised to find the most efficient solutions to reduce emissions. As of today, around 22% of the world's greenhouse gas emissions are covered by a carbon price. The carbon price varies from USD 1 per tonne to USD 127 per tonne CO_2 e. For the European power sector, the industry sector, large-scale heat and intra-EU aviation, the carbon price is set by the EU Emissions Trading System (ETS). In the ETS, the emission allowances are determined according to an emission cap that is reduced every year[50]. In connection with the European Green Deal, the European Commission is considering expanding the scope of the scheme to more sectors and increasing the overall ambition.

In addition to the ETS, several European countries have introduced carbon pricing for other sectors as well. Germany has a national climate target of 55% in 2030, and last year they decided that carbon pricing will be introduced to the transport and heating sectors from 2021. The carbon price will gradually increase from EUR 25/tonne CO_2. Meanwhile, the UK has decided to leave the EU ETS and will most likely introduce a separate national emissions trading scheme as part of the Brexit negotiations, but with the possibility of later linking to the European emissions trading scheme.

To better understand the effect of carbon pricing as a policy instrument for the European energy transition, we have looked more closely at the impacts of different carbon prices across sectors and geographies to 2050**.

Our analyses show that effective carbon pricing *accelerates* the reduction in emissions in all sectors***. This is because carbon pricing constitutes a more direct signal for changing behaviour within a given period of time. The transition in Europe will therefore be quicker if high climate ambitions are combined with effective carbon pricing.

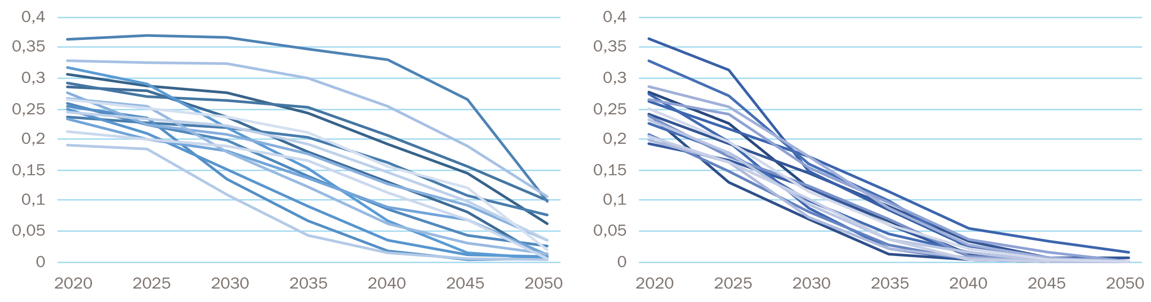
Carbon pricing in the European emissions trading market is harmonised across countries, which contributes to a more level playing field for the market players involved. We have analysed what happens if the carbon price varies across countries and regions within sectors that have a common EU climate target. The analyses show greater variation in emissions per energy use (tCO2/TWh) within a sector across countries with different carbon prices, and the gap widens over time.
A common carbon price across countries will have the opposite effect, and emissions per energy use in both the power and industry sectors will converge towards 2050 (Figure 30). All else being equal, greater variation in carbon pricing could result in increased carbon leakage of goods and products, but also changes in import

*This is based on our European energy system model. Changes in costs for cross-country interconnectors are included, but changes in costs for regional, local power grids and energy efficiency are not.

**Analysis assumptions: Three possibilities have been analysed for explicit carbon pricing in addition to common EU climate targets: i) One common carbon price across all countries and sectors, ii) Higher carbon price for ETS than for non-ETS sectors, iii) Higher carbon price for some 'leading' countries than for the rest of the EU. Results from these possibilities are compared with each other and with the Low Emissions Scenario. Carbon prices vary from 0 to 200 EUR/tCO_2. We have not conducted a complete policy instrument analysis.

***'Efficient carbon pricing' is defined as a carbon price on a par with the marginal costs of reducing emissions to the extent that the carbon price has a real effect.

30 Heat use in industry: Emissions per energy use per country ($MtCO_2/TWh$). (Differentiated carbon pricing between countries in graph to the left and homogeneous carbon pricing between countries in graph to the right).



and export of power across the EU.

Market players in countries with higher carbon prices may experience adverse competitiveness effect towards market players with a lower carbon price*. Differentiated carbon pricing should thus be a result of a conscious decision by some countries to take on a greater responsibility for the emission reductions in the EU.

In a perfect market, *one common carbon price* across *all* sectors in Europe will be the best socio-economic alternative, since the least expensive emission reductions are implemented first within a very large market. In this event, all greenhouse gas emissions would be subject to the same cost and all market players would have the same incentives. It can therefore, in principle, be described as straightforward, fair and unambiguous.

In reality, however, it is not quite that straightforward. Measures that have high initial investment costs and take a long time to build, such as infrastructure projects, often have to be implemented in parallel with other measures in order to have the desired climate effect. Another challenge is that carbon pricing primarily affects operating costs and life cycle costs, but in some cases the initial capital costs will be just as important for investment decisions. This normally applies, for example, when people are going to buy a new car or invest in new heating solutions or energy efficiency measures for their home. Many technologies in the early stages of development, before they are commercially profitable, might also need other policy instruments. In such cases, it is crucial that these other policy instruments do not weaken the effect of the carbon pricing instrument. In the ETS, where the price is determined by the supply-demand balance, it is important that allowances are cancelled in order to neutralise any negative effect on the carbon price from other policy instruments**.

In summary, our analyses show that efficient carbon pricing together with a strengthened climate ambition can accelerate the reduction in emissions. More harmonised carbon pricing across countries is better in terms of competitiveness between countries because emissions per energy use (all else being equal) converge over time within a sector. In principle, a common carbon price across all sectors will facilitate a more cost-effective transition, but this assumes perfect markets. A potential design change and expansion of the EU ETS to other sectors should be thoroughly assessed, taking into account carbon price efficiency, distributional effects, and administrative costs. In some cases, such as infrastructure development or for immature technologies, other policy instruments will be needed in addition to an emissions trading market. In these cases, any negative effect on the carbon price caused by other policy instruments should be neutralised to ensure that the carbon price remains effective.

Barriers to electrification in buildings, industry and transport increase the use of emission-free hydrogen

The electrification volumes in the Low Emissions Scenario assume that charging infrastructure and power grids are rapidly built out and evenly distributed geographically, combined with rapid uptake of electric heat pumps in the buildings and industry sectors. In this section, we look at the consequences for Europe's energy transition if any of these assumptions meet barriers.

In the Low Emissions Scenario, power demand in Europe will increase by more than 60% between now and 2050. The electricity share of total energy use in the transport, buildings and industry sectors in 2050 will be 30%, 66% and 81% respectively. Although our analyses show that this is the most cost-effective transition in terms of meeting the climate targets, it does not mean that this is where we end up. Electrification volumes at levels described in the Low Emissions Scenario require significant grid build-out across Europe. Some countries, such as Germany, have experienced clear opposition to new transmission line build out from Northern Germany to the south, which has slowed down the decision-making processes[51]. In addition, it is assumed an expansion of charging infrastructure that is rapid and evenly distributed geographically, and a rapid transition to electric heat pumps in the buildings and industry sectors. Switching to electric heat pumps is partly dependent on national tariffs and tax structures. Retail electricity prices in some countries can make it more expensive for consumers to use electricity instead of fossil fuels for heating. If barriers arise in one or more of these areas, direct use of electricity will be impacted. We have therefore analysed in more detail how Europe can still meet its climate targets when limiting the direct use of electricity in buildings, transport and the industry sector. We end up with an electricity share in 2050 of 26%, 51% and 70% respectively for transport, buildings and industry, which is significantly lower than in the Low Emissions Scenario (Figure 31)***

22 %

Twenty-two per cent of the world's greenhouse gas emissions are currently covered by carbon pricing

MORE

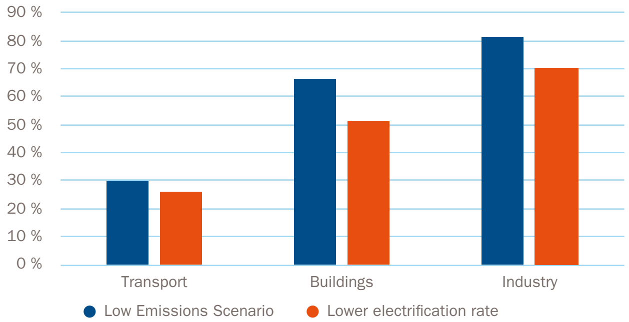
electric heat pumps in both the buildings and industry sectors

*Carbon leakage is when emission reductions in one country lead to increased emissions in another country, for example if an industry moves production to a country where it is less costly to emit greenhouse gases. In addition to carbon pricing, other factors such as national energy and industrial policy, as well as local costs and resources, will also play a decisive role when it comes to carbon leakage and emissions per energy use.

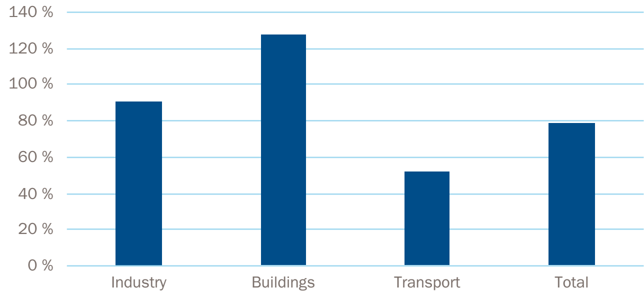
**In cases where there is an overlap of policy instruments in the sectors that are subject to emission allowances, the demand for EUA allowances is reduced, which in turn pushes down carbon prices. In order to rebalance the emissions trading system, the supply must therefore be adjusted down (cancelled) accordingly, so that the various policy instruments and the emissions trading system reinforce each other, and the effect is neutralised.

***Analysis assumptions: Heat demand in buildings has a limitation (in %) to how much energy (end use) that can be covered by electric heat pumps and direct electric heating, and the same applies for direct electricity use in industry and electric cars.

31 Share of electricity per sector in 2050 in the Low Emissions Scenario compared with the Lower electrification rate case (%)

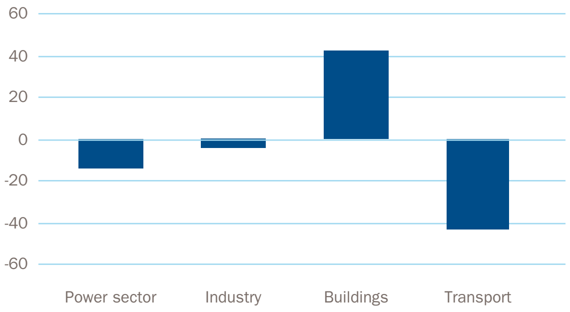


32 Percentage increase in hydrogen use in the Lower electrification rate case compared to the Low Emissions Scenario (%)

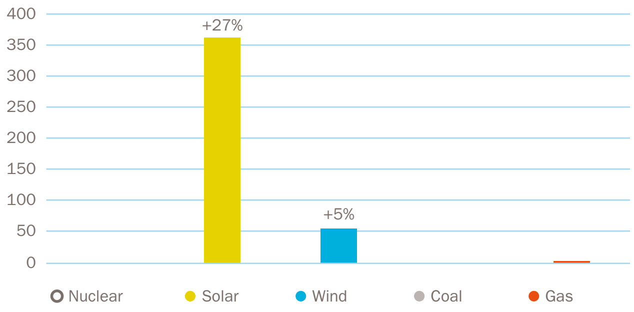


COAL POWER PLANT in the city of Bełchatów, Poland

33 Changes in emissions per sector in 2050 in the Lower electrification rate case compared to the Low Emissions Scenario (Mt CO_2)



34 Changes in installed capacity (GW) in the Lower electrification rate case compared to the Low Emissions Scenario.



At the same time, we see that hydrogen use will increase by 80% compared to the Low Emissions Scenario (Figure 32). Emission-free hydrogen will be introduced on a large scale towards the end of the period, and the fossil fuel phase-out will continue after direct electrification stalls*.

Limited use of heat pumps in the buildings sector will see hydrogen use double, and there will be a small increase in natural gas to cover the demand for heating. Due to lower efficiency for hydrogen, final energy use in the buildings sector will be 25% higher with fewer heat pumps than in the Low Emissions Scenario. Consequently, the buildings sector will be more expensive to decarbonise, and both the transport and power sectors will have to reduce their emissions further compared to the Low Emissions Scenario in order to meet the climate targets in the most cost-effective way (Figure 33).

Since hydrogen has a higher efficiency loss, increased use of green hydrogen will result in a larger growth of renewable installed capacity, particularly solar PV capacity installed close to demand, according to our analyses. Compared to the Low Emissions Scenario, a lower electrification rate will mean almost 360 GW of extra installed solar power and 54 GW more wind power capacity in Europe (Figure 34).

Overall, the analyses show that in a cost-optimal transition where direct electrification encounters barriers, emission-free hydrogen will play a key role. Increased use of green hydrogen will mean a greater need for renewable electricity than with direct electrification. The results show that, when direct electricity is limited, the sectors that can most easily implement efficiency measures and switch to hydrogen will take larger shares of the emission cuts. In our analyses, energy system costs will be 1.5% higher over the period compared to the Low Emissions Scenario.

Slower coal phase-out in Europe results in more renewable energy

In Europe, as in the rest of the world, some countries are more sceptical to a rapid transition, since the economy is strongly linked to the fossil industry. In this section, we see that if a delayed coal phase-out is allowed in some European countries, Europe will need greater electrification and more renewable electricity in order for the climate targets to be met.

In the analysis, we have assumed that several European countries will be allowed to phase out coal power at a slower pace, while the EU will achieve the same climate ambitions as in the Low Emissions Scenario with a 90% reduction in emissions by 2050**. A decelerated phasing out of coal in the power sector would require more substantial emission reductions in other sectors. This would lead to an increase in the use of electricity in the buildings, industry and transport sectors.

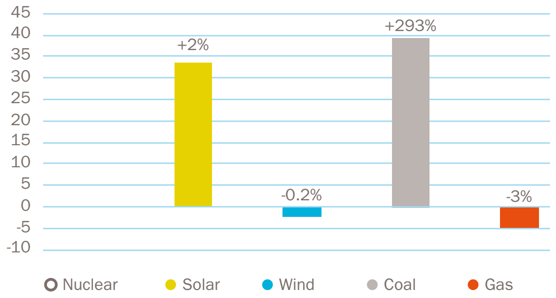
A higher electrification rate will push up the demand for power relative to the Low Emissions Scenario. This means that the capacity for coal and renewable power will both increase, even though this may at first seem self-contradictory (Figure 35). As we approach 2050, it will also be necessary to reduce coal consumption in order to meet the climate targets. We will then be left with coal power plants that eventually end up as stranded assets.

In this analysis, we see that a slower coal phase-out requires a more rapid transition of transport and heating in buildings and industry. A postponed transition for the coal industry in some European countries may shift the burden and accelerate the transition of the automotive industry and the buildings sector in other countries.

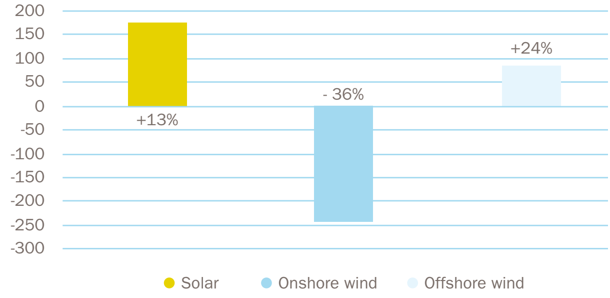
*Green hydrogen makes up over 70% of the hydrogen production in 2050 in our analyses, and much of the hydrogen is generated close to demand, which reduces the need for infrastructure. There will also be a need for blue hydrogen, particularly in a transitional period.

**Analysis assumptions: Extended use of coal power plants is assumed over the time horizon in Poland, Germany, the Czech Republic, Slovakia, Hungary, Romania, the Balkans, Spain and Portugal. Existing coal power plants are assumed to have a longer lifetime, and the coal phase-out per year per country is limited.

35 Changes in capacity in the power sector (GW) due to a decelerated coal phase-out. Percentage change from the Low Emissions Scenario.



36 Changes in renewable capacity (GW) in the power sector due to more limited growth of onshore wind power (percentage change from the Low Emissions Scenario)



Barriers to onshore wind power build-out: other solutions for the energy transition

If the build-out of onshore wind power meets barriers, while the EU climate target remains, our analyses show that more solar PV and offshore wind capacity will be built. This in turn will have two important consequences: The transition will become more expensive, and the cross-border interconnector capacity in the EU will increase.

In most countries, the population will have strong opinions on energy costs, the building of infrastructure and impacts on nature. Most countries will therefore have some degree of opposition to the energy transition. According to research, opposition to climate policy will intensify if the policy is unclear, if it is perceived as socially inequitable or if it will impact vulnerable nature. Similarly, opposition increases if climate measures significantly impact people's finances[52]. There have been massive demonstrations in several countries the last years against higher petrol taxes and road tolls, as well as new wind power projects.

In the Low Emissions Scenario, onshore wind power will account for around a quarter of the total installed power capacity in 2050 in Europe. This represents a cost-optimal decarbonisation pathway for Europe as a whole. If opposition to onshore wind power increases in several countries, while the EU's overall climate ambition remains, Europe will need other climate solutions. We have analysed the consequences of having to limit onshore wind power build-out, while the EU maintains the same climate targets and also seeks the most cost-effective transition possible*.

Our analyses show that an energy transition where onshore wind power capacity is limited to one third of the capacity in the Low Emissions Scenario in 2050, will lead to further build-out in other renewable sources. Both solar PV and offshore wind power will offset the loss of energy production from onshore wind. The demand for power will remain the same and some additional gas power will be needed in the power mix. We also see that the battery capacity will increase to meet a higher need for flexibility in the power system because of the higher share of solar PV.

Our analyses also show higher greenhouse gas emissions towards 2030 and somewhat more emission-free hydrogen in the other sectors towards 2050. The need for physical interconnections between power systems will also change. Physically integrated power markets between areas can benefit from the differences in the power systems and can increase access to flexible solutions. The higher share of variable solar PV and wind power in the European power systems increases the need for cross-border interconnection to provide flexibility and ensure security of supply. In the Low Emissions Scenario, the interconnector capacity in Europe will increase by 30% between now and 2050. In a power mix where onshore wind build-out is limited and is replaced by more solar PV and offshore wind power, the need for interconnector capacity will be 5% higher on average over the period.

Overall, we see that barriers to onshore wind power build-out will lead to greater build-out of solar PV and offshore wind power. Furthermore, the costs of the transition will increase, and cross-border interconnections will become increasingly important. Increasing costs and cross-border interconnectors may in turn give rise to new opposition.

*Analysis assumptions: A more limited expansion of onshore wind power has been assumed in some European countries. This will reduce installed capacity (GW) for onshore wind in France, Germany, the UK, Greece, Spain, Portugal, Italy, the Netherlands and Poland.

BAILLE WIND FARM, in the Scottish Highlands

Summary: Aiming for a socially equitable and cost-effective energy transition

In the Low Emissions Scenario, we will end up with an energy system that has lower costs per capita than today. However, the transition is not without challenges. A key prerequisite for meeting the climate targets is sufficient public support. In addition, unforeseen events, such as the COVID-19 pandemic, can affect the pace of the energy transition. The outcome of the pandemic can lead to long-term changes in behaviour, with people travelling and consuming less, and this in turn could accelerate the energy transition to a greater extent than assumed in the Low Emissions Scenario. The outcome may also be the opposite, with less international cooperation and a slower energy transition globally. Now that the world is starting to recover from the COVID-19 pandemic, predictable policy ambitions and forward looking investments are needed for a rapid and cost-efficient energy transition.

One of the biggest challenges for the energy transition is how benefits and costs are distributed in the society. In the Low Emissions Scenario, we will end up with an energy system that has lower costs per capita and per GDP than is currently the case. Nevertheless, the transition is not without its challenges. While some countries, social groups and individuals may benefit from the transition, some may be disadvantaged. A fair distribution of costs and benefits will be key. Having sufficient public support is a prerequisite for achieving the rapid energy transition needed to meet the climate targets.

It will also be key to provide a good, predictable framework for the transition. Our analyses show that ambitious, predictable climate targets, together with markets and effective carbon pricing can accelerate the energy transition and reduce emissions quicker than climate ambitions alone. There is an urgent need to produce more renewable electricity and to decarbonise transport, buildings and industry sectors through electrification. These climate solutions can quickly outcompete fossil alternatives. In applications where direct electrification meets challenges, other climate solutions will be needed. Emission-free hydrogen and ammonia can play a major role in these "hard-to-abate" applications. To speed up decarbonisation in these areas, greater policy support will be needed. The world has a lot to learn from Europe's new growth strategy, the European Green Deal. The strategy is holistic. It seeks to strengthen markets and revamp the European industry, whilst focusing on a just transition.

The COVID-19 pandemic may lead to major structural changes in society that affect the global energy markets. Lockdown measures have reduced travelling, increased the use of digital solutions and resulted in a sharp fall in consumption. If the measures lead to permanent changes after the restrictions are lifted and the pandemic is over, the long-term effects on the energy systems may be greater than what is assumed in the Low Emissions Scenario. Permanent shifts in daily-life habits, behaviour patterns and the transport of goods and people may accelerate the transition. Such permanent changes can be intensified as a result of green recovery packages. Which in turn can garner more support for climate policy. However, there is also a risk that the pandemic has created fear in the population that could lead to increased protectionism and more political tension in the world. There is a risk that the existing global institutions will be weakened. These play an important role in solving the climate crisis. Global decarbonisation in line with or faster than Statkraft's Low Emissions Scenario requires global trade and climate policy to support and not hinder the energy transition.

In the event of specific barriers to specific decarbonisation solutions, such as the build-out of renewable capacity, delayed coal phase-out or more limited electrification, our analyses show that there are alternative solutions, but in general these will make the energy transition more costly. If one sector meets challenges, the consequences are either that climate targets are not met or that other sectors will have to take on a larger burden of the emission reductions. Similarly, if the long-term climate targets are unpredictable, there is a risk of wrong investments and a more costly transition. Now that the world shall recover from the COVID-19 pandemic, predictable ambitions, cost-effective solutions and forward-looking investments are needed.

Even if the energy transition encounters various barriers, our analyses show that there will still be a great need for more renewable power and emission-free hydrogen if Europe is to meet its climate targets. Significantly more renewable energy is needed to decarbonise the power sector and to switch from fossil fuels to electricity in the transport, industry and building sectors. Developments in the power sector have taken place at a surprisingly rapid pace in the last ten years. In particular, we have seen major cost declines and growth in solar PV, wind power, electrolysers and batteries. This shows that rapid change is possible when policy, markets and technology move in the same direction.

APPENDIX: Key parameters and assumptions

Table 1. Key parameters in Statkraft's Low Emissions Scenario compared with IEA, IRENA and DNV GL*

Sectors	Statkraft's Low Emissions Scenario 2020	Statkraft's Low Emissions Scenario 2019	IEA STEPS (2019)	IRENA REmap (2020)	IEA SDS (2019)	DNV GL ETO (2019)
Annual avg. growth in primary energy demand 2018–50	0.0%	0.3%	0.98% (to 2040)	-0.20%	0.30% (to 2040)	-0.09%
Power sector (annual average growth 2018-50)						
Demand	2.5%	2.5%	2.03% (to 2040)	2.35%	1.70% (to 2040)	2.43%
Wind power	8.3%	8.5%	6.66% (to 2040)	8.95%	8.90% (to 2040)	8.84%
Solar power	12.0%	12.5%	9.88% (to 2040)	10.98%	12.0% (to 2040)	11.91%
Hydropower	1.5%	1.6%	1.71% (to 2040)	1.87%	2.30% (to 2040)	1.87%
Fossil share in the power sector (TWh, 2050)	12.0%	12.0%	48.0% (in 2040)	14.1%	21.0%	18.0%
Primary energy						
Oil consumption: Annual growth 2018–50	-1.8%	-1.7%	0.41% (to 2040)	NA	-1.8% (to 2040)	-1.83%
Gas consumption: Annual growth 2018–50	0.3%	0.4%	1.40% (to 2040)	NA	-0.2% (to 2040)	0.42%
Coal consumption: Annual growth 2018–50	-3.5%	-3.2%	-0.05% (to 2040)	NA	-4.3% (to 2040)	-3.21%
Global energy-related CO_2 emissions ($GtCO_2$) in 2050	17.6	18.0	35.6 (in 2040)	9.8	15.8 (in 2040)	20.8

*The scenarios are based on different assumptions and are therefore not directly comparable. Both the IEA STEPS and DNV ETO scenarios are reference scenarios. Statkraft's Low Emissions Scenario is a technologically optimistic and realistic scenario. The IRENA REmap and IEA SDS scenarios are based on a desired climate target and and analyse how it can be achieved.

Assumptions in Statkraft's Low Emissions Scenario

Statkraft's Low Emissions Scenario extends current global energy trends and shows a realistic, optimistic view on the energy transition up to 2050.

The scenario is based on the expansion of known technologies and on Statkraft's own global and regional analyses. The scenario is not based on a linear projection of current trends, nor does it base itself on a given climate target and perform a backward analysis from this. The analyses assume the same trends as all other Statkraft analyses.

The Low Emissions Scenario analyses the cost developments for known technologies up to 2050, including renewable power production, batteries, emission-free hydrogen, etc. We are assuming a continued steep drop in the cost per MWh and a high rate of expansion until around 2030. After this, the decline in costs slows down somewhat, first for wind and then for solar energy. This corresponds to a realistic, but optimistic assumption.

In the Low Emissions Scenario, we assume increased focus on regional value chains, but with a continued significant global dependency and global trade in goods and services related to the energy transition. Statkraft's Low Emissions Scenario assumes that global trade and climate policy will support the energy transition.

The analyses are based on internal models as well as in-depth studies of external sources.

Statkraft's Low Emissions Scenario has been prepared by Statkraft's strategic analysis team in cooperation with experts in other fields. More than 50 analysts are involved in market analysis in Statkraft.

The scenario combines a global energy balance model and a European energy system model with detailed power market models in the countries in which we are active. Statkraft models power markets in detail, hour by hour, for the Nordic countries, Europe, India and countries in South America up to 2050. The European energy system model assumes that the most cost-optimal solutions for Europe are chosen. Cost optimisation is applied across regions and sectors.

The analyses for Europe were conducted by Statkraft in collaboration with T. Burandt, K. Hainsch and K. Löffler (Technische Universität Berlin), based on an adjusted version of GENeSYS-MOD (Designing a Model for the Global Energy System — GENeSYS- MOD: An Application of the Open-Source Energy Modeling System (OSeMOSYS) by Konstantin Löffler, Karlo Hainsch, Thorsten Burandt, Pao-Yu Oei, Claudia Kemfert and Christian Von Hirschhausen (2017).

For energy-related CO_2 emissions, the analyses were conducted in collaboration with Glen Peters, Research Director, CICERO, and the climate scenarios are taken from IAMC 1.5°C Scenario Explorer from IIASA (version 1.1) (*https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/*), analysed in Rogelj, Shindell, et al, Mitigation pathways compatible with 1.5°C in the context of sustainable development, in 'Special Report on Global Warming of 1.5°C (SR15)', Intergovernmental Panel on Climate Change, Geneva, 2018 (*http://www.ipcc.ch/sr15/*), Statkraft analyses and IEA World Energy Outlook 2019.

COVID-19 and assumptions concerning global energy demand

The starting point for the analyses is economic growth and population growth in line with a market consensus. Global parameters are calibrated to historical data in line with IEA World Energy Outlook 2019.

In the Low Emissions Scenario, we have assumed that the global economy will decline and then grow from a lower level following the pandemic. Although the growth rate in the economy will recover, the global economy and demand for energy are expected to remain lower over the entire period compared to expectations before the pandemic. The effects of the pandemic will gradually diminish leading up to 2050. It is not assumed that the COVID-19 measures will lead to major permanent behavioural changes after the restrictions have been lifted and the pandemic is over. Structural changes can however have greater lasting effects on the energy systems globally than assumed in the Low Emissions Scenario. There is a lot of uncertainty regarding the future at this point, and the pace of the transition could either accelerate or decelerate as a result of permanent changes after COVID-19.

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