Global energy trends

Statkraft's Low Emissions Scenario 2018

Statkraft

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The energy sector is in the midst of a rapid transition with profound technological, political and market-based changes. In order to deepen our understanding of market trends, Statkraft develops long-term scenarios that provide insight into how global energy markets could transition in the future.

This is the third year in a row that we publish one of these scenarios, called the Low Emissions Scenario. The scenario is based on well-known technologies and builds upon Statkraft's own global and regional analyses and models, as well as in-depth studies by numerous external sources. This scenario is one of several that inform Statkraft's strategic decisions.

Dramatic falls in renewable technology costs have led to increasing deployment, which in turn reinforces the downward pressure on cost levels. The Low Emissions Scenario is an optimistic but realistic scenario, which assumes that this trend will continue and that a further decline in renewable energy and battery costs will drive the rapid increase of renewable energy, going forward. The outcome is a world where low-carbon electricity can be used to electrify large parts of the economy, including the transport, buildings and industry sectors. This will not only increase electricity demand but also lead to a more integrated energy system.

Statkraft has purposely not created a scenario that uses a climate target as an end point and then analysed «what does it take?» to get there. However, a key finding of the analysis is that it is possible, with a rapid increase in renewables and electrification, to limit global emissions to levels that are consistent with a 2 degree pathway. The timeframe of the analysis goes out to 2040 and emission levels beyond 2040 need to continue on a downward trajectory according to IPCC scenarios[1], even more so if a 1.5 degree pathway is to be achieved.

The developments over the past few years have been exponential, for example the increase in solar PV capacity installed annually. A linear extrapolation is therefore expected to grossly underestimate the pace of the energy transition. Statkraft is confident that the development towards a much cleaner global power sector is inevitable. Therefore, a more important question is «how quickly will this development happen?».

The scenario assumes that policy and regulation will continue to play an important role in the speed of the transition, although the improved economics of renewable energy is the main driving force in this scenario. Climate and energy policy measures can come as a result of multilateral cooperation, but also as a result of national climate ambitions, local environmental issues and energy security concerns.

One of the key challenges for the development towards a renewable energy sector is the requirement for increased flexibility in power systems as a result of high levels of intermittent generation. Solving the flexibility challenge in a cost-effective and environmentally-friendly way is key to the development of a renewable-dominated power system. Therefore, the focus of the last section in our report this year is on the different forms of flexibility available and how the flexibility challenge in the power sector can be solved, with an emphasis on the European market.

[1] Compared with the IPCC scenarios, RCP 3.4 and RCP 2.6 (http://www.ipcc.ch).

Solar and wind power are changing the rules of the game for the power markets. Photo: Getty Images/deliormanli

Key findings from **Statkraft's Low Emissions Scenario 2018:**

Renewables and electrification lowering global emissions

- ➔ The power sector globally reaches a renewable share of 70 per cent by 2040.
- ➔ In 2040 solar power will become the largest source of power generation on a global basis and cover almost 30% of all electricity generation. Wind power will cover 20%.
- ➔ Solar and wind power will be cheaper than other new power generation capacity globally. In areas with good wind and solar resources, new solar and wind power will be cheaper than *existing* coal- and gas power production.
- ➔ By 2040, electricity will cover over 30 per cent of energy consumption in the buildings, industry, and transport sectors. The scenario expects that 77 per cent of all new passenger vehicles sold will be fully electric in 2040.
- ➔ Energy-related greenhouse gas emissions in 2040 will be about 30 per cent lower than today with emissions following a pathway that is consistent with the two degree target.

Demand for flexibility increasing within the power markets

- ➔ The carbon intensity of the power sector falls by 80 per cent by 2040 as renewables displace thermal generation. Most of the renewable growth comes from intermittent sources, namely solar and wind power.
- ➔ The need for flexible solutions increases significantly with the growing share of intermittent generation. There will be major differences at a national level.
- ➔ Countries with a high share of solar power will require more short-term flexibility within a 24 hour period. A high level of competition is expected between the many different solutions that can be adopted. In India, for example, over 80 per cent of the flexibility is expected to be short-term.
- ➔ Countries with a high share of wind power will require more long term flexibility lasting up to two weeks. There are fewer solutions to solve the long-term flexibility requirement. In Germany and the UK, for example, around 60 per cent of the flexibility could come from long-term solutions.

Background: New milestones for climate and green technology

Over the years we have seen a number of strong trends within technology development and changes to the climate. This was also the case in 2017.

2017 – the year of record high temperatures

Last year was one of the three warmest years ever recorded, where the global temperature increased to 1.1°C above pre-industrial levels. The global temperature for the last five years was the highest five-year average on record. There is now increasing focus on the costs associated with a changing climate. The total disaster losses (in USD) from weather and climate-related events in 2017 were the largest annual total on record. In the course of the year, 30 per cent of the world's population was exposed to extreme heat waves and 41 million people were affected by flooding in South Asia [2]. Global energy-related emissions increased for the first time in three years to new record levels. Emissions increased in Asia and the EU, but fell in other places like the USA and Mexico.

Investments in renewable energy continue to surpass investments in coal and gas power

In 2017 the power sector added a record of 167 GW of renewable energy capacity globally, up 8% from the year before. A quarter of all electricity produced now comes from renewable sources. China and the USA accounted for around half of the growth in renewable energy production, followed by the EU, India, and Japan. As in previous years, investments in renewable energy production exceeded investments in coal and gas power. Solar and wind power are rapidly becoming the cheapest technologies in several regions. China broke all records with over 50 GW of new solar power capacity in 2017. This exceeded the increase of Chinese gas, coal, and nuclear power capacity combined [3].

Subsidies for renewables are being gradually removed whilst auctions are becoming more prevalent. Due to the high costs of solar PV and wind historically, investors have largely relied on fixed-price subsidies in order to secure investments. As technology costs have fallen dramatically, subsidies have been removed or changed so that solar and wind power investors are, to a greater extent, exposed directly to the power price. This makes their income risk more complex. Government-controlled auctions with a form of a minimum pricing have become a widely used tool in countries that previously offered fixed-price subsidies. There is also an emergence of projects being built without the need for government support.

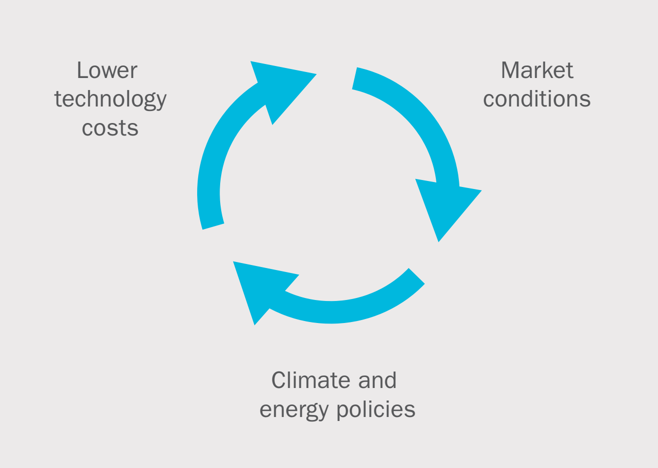


Figure 1. The Low Emissions Scenario assumes a reinforcing cycle between markets, policies and technologies.

Demanding future for the coal industry

It is becoming increasingly difficult to fund new coal projects. Banks have reduced their loans to the coal industry by 44 per cent since 2015. The 15 largest banks in the world, including JPMorgan, Societe Generale and Deutsche Bank have implemented restrictions on financing coal projects. Major investors are increasingly moving away from fossil fuel investments and towards renewables. This trend is also related to banks, insurance companies, and investors systematically factoring in climate risk to their investment decisions.

According to the World Health Organization (WHO), around seven million people die annually from air pollution. In order to improve the enormous air quality problem in the cities, the Chinese authorities implemented stricter measures to curb emissions from coal. Coal power plants are facing difficult times. Global power plant retirements exceeded 25GW in 2017, a new record. At the same time, new completed coal power plants dropped by 28 per cent compared to last year [4].

Greenhouse gas emissions do not follow economic growth

A positive development over the past years has been that greenhouse gas emissions have not followed the growth of the

[2] World Meteorolgical Organization (https://public.wmo.int)
[3] Frankfurt School UNEP (http://fs-unep-centre.org) and Irena (www.irena.org)
[4] Source: endcoal.org

global economy. This decoupling of economic growth, energy use, and global emissions, continued in 2017. From 2010 until today, the global economy has on average increased by 2.8 per cent per year. In comparison, the annual primary energy consumption in the same period only increased by 1.6 per cent, and global emissions by 1.1 per cent. In spite of record high growth in renewable energy, fossil fuel continues to account for 80 per cent of global energy consumption. This explains the record high CO_2 emissions in 2017.

Strong global electrification trend

Electricity demand has grown on average by 2.4% per year since 2010 and is growing faster than total final energy demand. Electrification is a global trend, particularly within the transport sector. Electric passenger vehicle sales increased by 70 per cent in the first quarter of 2018 compared to the corresponding period the year before. China continues to lead with 43 per cent of the electric passenger vehicle market. In Europe, electric passenger vehicle sales grew by 37 per cent in the same period. In 2017 there were close to 400 000 electric buses on the road, mainly in China [5]. These developments are already having a small impact on oil demand.

Persisting uncertainty within climate policy

2018 is an important year for international climate policy. The first «facilitative dialogue» will be carried out in the autumn. The purpose of this is to take stock of current progress and prepare for new national contributions. At the same time the IPCC is issuing a new report on the impacts of global warming of 1.5 degrees [6]. New national contributions to the Paris Agreement will be submitted during the course of 2020. This will be the first step of the five year «ratchet mechanism» in accordance with the Paris Agreement [7]. The national contributions will demonstrate whether countries are capable of collectively driving the global climate efforts forward through gradually increasing ambitions. This is especially challenging since international negotiations are affected by the absence of US leadership. The USA was the only country which chose to exit the Paris Agreement last year, and further proposes a plan to subsidise unprofitable national coal power plants. It is uncertain who will take over the USA's position in terms of leadership. There are positive signals from China, the EU, and India that suggest they will drive international climate efforts in the right direction.

There has also been progress internationally in the maritime sector. The UN organisation IMO [8], reached a global agreement to halve the sector's greenhouse gas emissions by 2050, with the ambition of moving towards zero emissions. The agreement came after several years of intensive negotiations and was a significant milestone.

At the same time, there are positive developments at national and regional levels. There are currently 47 carbon pricing mechanisms in the world. With China implementing a national carbon market, over 20 per cent of global emissions will be covered by carbon pricing [9]. Another positive climate policy measure is that over 20 countries, including the UK, Canada, France, Finland, and Mexico have joined forces to phase out coal power [10]. Moreover, several countries, including India and China, announced that they will ban the sale of fossil fuel vehicles. In the EU there was also major progress in their energy and climate policies. The EU has agreed on new targets for 2030, with a 40 per cent climate target, 32 per cent renewable target, and a 32.5 per cent energy efficiency target. They are now developing common measures and regulations to achieve these targets. These include strengthening the emissions trading scheme (EU ETS) and strengthening the framework for integrated energy markets.

Not only countries, but also companies, are driving the world in a more climate-friendly direction. For example, private companies are assuming an increasingly important role in mobilising investments in renewable power. Companies like Ikea, Apple, and Facebook have declared that they will only buy renewable power. Along with over 130 other companies, they have joined the initiative RE100.org aiming to become 100 per cent renewable. In addition, cities play an important role. In 2017, over 9000 cities globally have committed to accelerate ambitious and measurable climate initiatives through the «Global Covenant of Mayors for Climate and Energy» alliance.

Figure 2. In 2017, 99 per cent of all electric buses globally drove on Chinese roads
Photo: Getty Images/winhorse

5 Source: Bloomberg

6 Intergovernmental Panel for Climate Change (www.ipcc.ch)

7 www.unfccc.int

8 International Maritime Organisation: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

9 World Bank: State and trends of carbon pricing 2018

10 «Powering Past Coal Alliance»: https://unfccc.int/news/more-than-20-countries-launch-global-alliance-to-phase-out-coal

Global Low Emissions Scenario:
A new energy world

In the Low Emissions Scenario we expect that costs related to solar and wind power will fall significantly towards 2040. Not only will solar and wind power be the first choice for *new* power production, they will also quickly become competitive with *existing* power generation such as coal and gas power in areas with good solar and wind resources.

The annual growth from 2016 to 2040 in wind and solar power production is 8 and 15 per cent respectively in the Low Emissions Scenario. This strong growth will require large investments and scaling up of the supply chain. This has profound consequences for the electricity sector and the dynamics of the power markets. A transition away from fossil fuels to renewables will also affect the global economy, including patterns of global trade and energy dependency.

Global energy balance: Moderate growth in energy demand. Greenhouse gas emissions follow a two-degree pathway

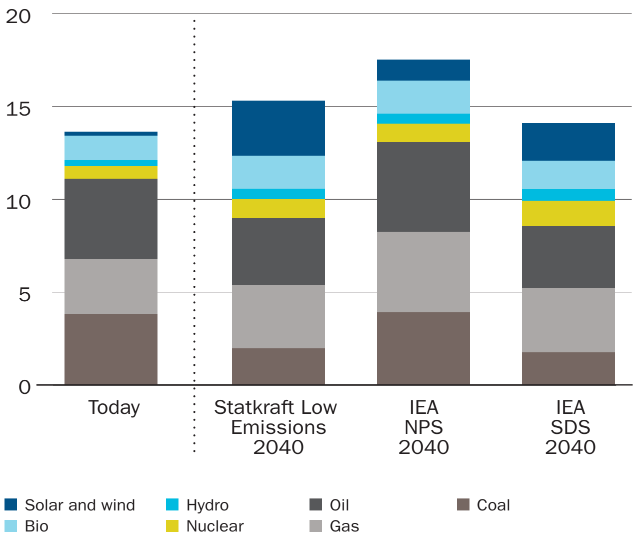
Towards 2040 population growth and increased living standards will lead to increasing energy use globally. At the same time, the Low Emissions Scenario expects significant energy efficiency improvement in all sectors and an accelerated growth in electricity use. This means that growth in energy use continues to decouple from economic growth. We see an average increase in primary energy consumption of 0.5 per cent annually from today that flattens out towards 0.1 per cent after 2035. Due to electrification, the growth in power demand will increase over four times more than final energy demand during the same period of time [11].

Electrification is an important energy efficiency and climate policy measure

In the Low Emissions Scenario, power demand continues to grow on average by 2.4 per cent per year from today until 2040. Moving to a clean power supply combined with switching from fossil to electrical processes leads to significant energy efficiency gains. For example, an electric engine in a vehicle is around 90 per cent efficient, which is three to four times more efficient than a conventional vehicle engine. Similarly, energy savings of around 60 per cent are possible when switching from fossil fuel heating to electrical heating by using heat pumps.

Fossil fuel demand is expected to be increasingly impacted by the higher share of renewables and electrification. Within the transport sector oil-products are gradually displaced by electricity, with the pace of this change picking up around 2030.

Global primary energy demand
Billions toe



Global energy related emissions
$GtCO_2e$

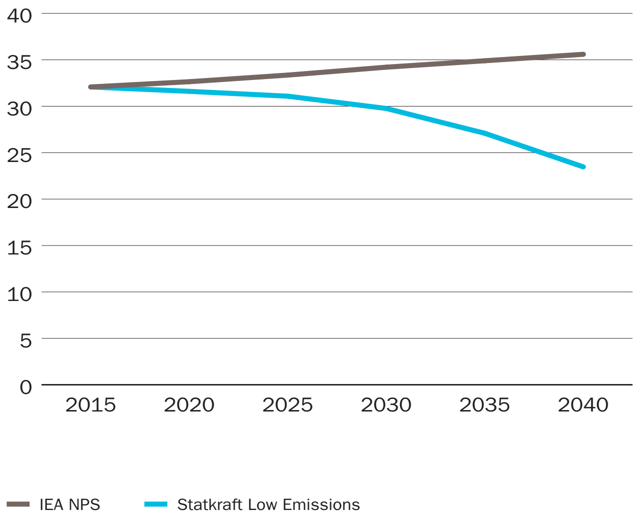


Figure 3. Global primary energy balance today and in 2040, and development in global energy-related greenhouse gas emissions. IEA17 and Statkraft Low Emissions 2018.

Renewable power globally
GW

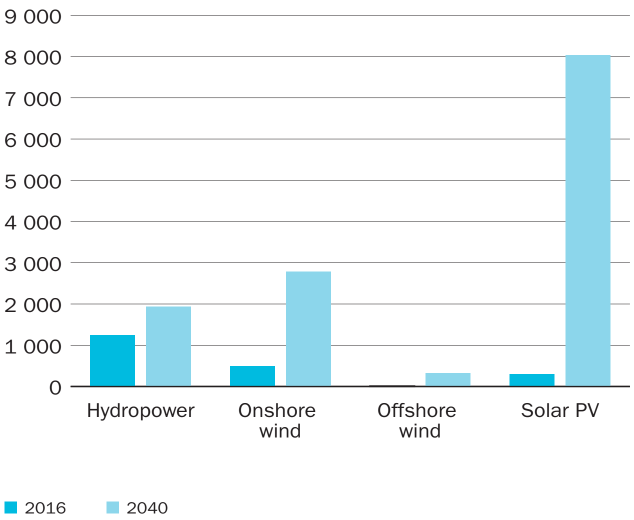


Figure 4. Growth in various forms of renewable power production (in GW installed capacity). The IEA (2016) and Statkraft Low Emissions (in 2040).

Annual average growth
Per cent, indexed from 2015

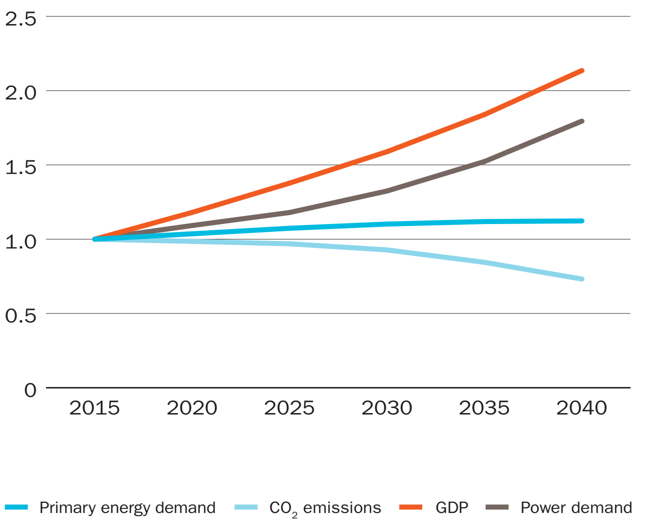


Figure 5. While GDP more than doubles towards 2040, primary energy consumption increases by only 10 per cent in the Low Emissions Scenario.

This results in oil demand peaking in the middle of the 2020s and falling by 18 per cent from today until 2040 in the Low Emissions Scenario. Coal is also heavily impacted with global coal demand dropping by 50 percent. This is due to both CO_2 pricing, direct regulations limiting coal power plants, and coal power losing cost competitiveness against renewable power. Gas consumption increases slightly during this time horizon, growing mostly within the heating and transport sectors, and providing flexibility in the power sector. At the same time we see that gas, as a flexible solution in the power sector, will face significant competition.

Implications for global greenhouse gas emissions

The developments in the Low Emissions Scenario result in decreasing global greenhouse gas emissions over the period. When around 70 per cent of power generation is covered by renewable sources globally by 2040, the emission intensity in the power sector is reduced by 80 per cent in our analyses. Today the power sector releases about 0.5 tCO_2 per MWh on average globally, while in 2040 this will be reduced to 0.13 tCO_2 per MWh.

A cleaner power supply means that there is significant potential to switch from fossil fuels to electricity in a wide range of areas. Electrification of the transport, industry, and buildings sectors contributes significantly to emission reductions. In the Low Emissions Scenario, this provides almost 5 Gt lower emissions by 2040 compared to IEA's reference scenario [12]. As an example, the electrification of heavy transport constitutes a six per cent reduction in oil demand and 1 Gt lower emissions compared to a scenario without electrification of heavy transport. With this change of pace, the energy related greenhouse gas emissions will follow a path consistent with the two degree target towards 2040. Policy measures in other sectors and measures after 2040 will play a crucial role to push emission levels further downwards by 2100 [13].

[11] IEA's approach is used in the conversion between primary energy consumption and final energy. Sources: IEA/OECD Statistical Manual (2005), BP Energy Outlook (2018).

[12] IEA World Energy Outlook 2017, New Policies Scenario (NPS).

[13] Compared with the latest IPCC scenarios.

Electricity share
In final energy (%) and absolute growth (TWh)

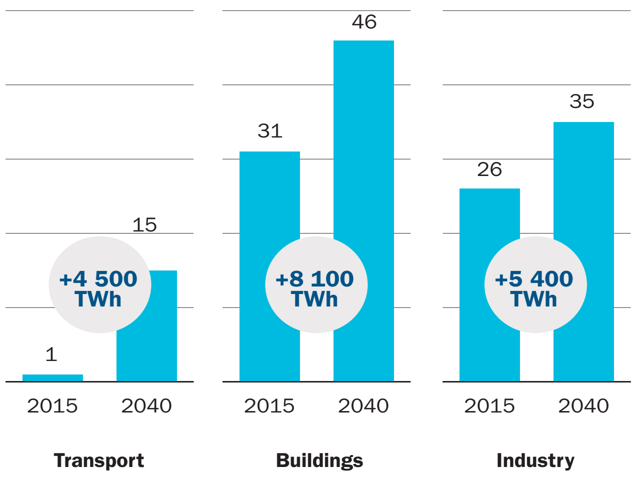


Figure 6. Growth in electricity consumption in transport, buildings and industry globally. Statkraft Low Emissions.

The electricity share will increase in all sectors

In the *transport sector* we see a massive cost reduction within battery technologies. This makes electric passenger vehicles competitive compared to conventional passenger vehicles within the next few years. This will quickly apply to most passenger vehicle segments in many regions across the globe. In addition, several countries, including India and China have ambitious electrification targets for the vehicle fleet. This has led to automakers increasingly shifting their focus from fossil fuel to electric passenger vehicles. Over 340 electric passenger vehicles models are planned leading up to 2025 (Bloomberg). An increased use of vehicle-sharing services, as well as the emergence of self-driving vehicles, will contribute to a more rapid shift towards an electric car fleet.

This scenario sees an exponential increase in the number of electric passenger vehicles going forward. In addition to economics, the rate at which power grids are upgraded, as well as national policy instruments, will impact how quickly this growth can happen. In the Low Emissions Scenario we expect a significant expansion of the charging infrastructure. We foresee a sharp increase in electric passenger vehicle sales from 2030 onwards that will result in 77 per cent of all new passenger vehicles sold being completely electric by 2040. In addition we assume that around 40 per cent of new vehicle sales within heavy transport are electric (including hydrogen). These are mainly buses or local goods transport in cities where local air pollution will be an additional driver of electrification. Also for shorter sea and air routes, we see some potential, but the impact by 2040 will be limited compared to land transport.

Expected battery cost development
USD/kWh storage capacity

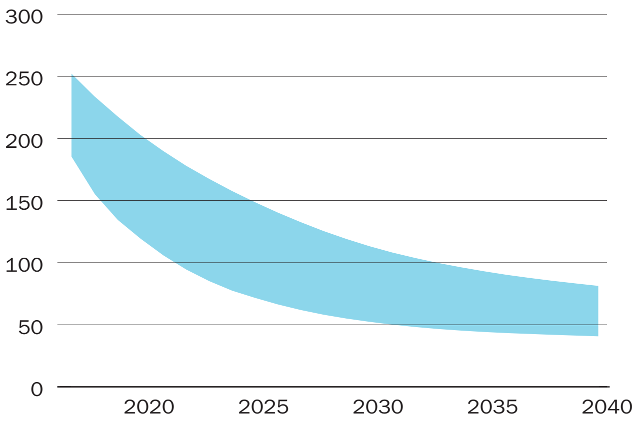


Figure 7. Rapid cost reduction for batteries will make electric passenger vehicles cheaper than conventional passenger vehicles in most countries within the next five years. Statkraft Low Emissions Scenario.

Electric vehicle sales
Per centage

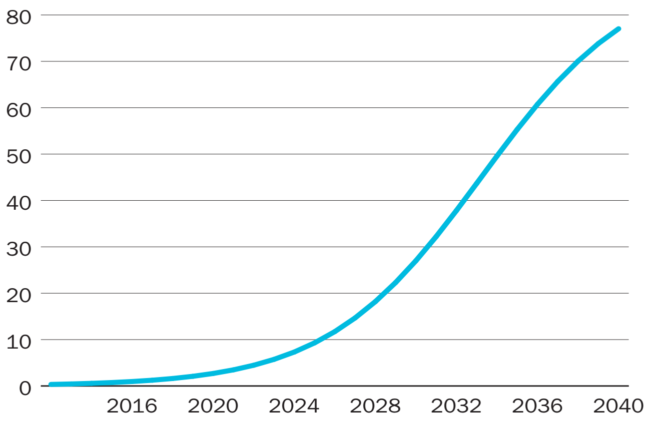


Figure 8. The share of electric vehicles in total global new car sales (passenger vehicles and smaller vans). Statkraft Low Emissions Scenario.

Several countries, including India and China, have high climate ambitions for their transport sector. Photo: Getty Images/wellphoto

We also expect to see substantial electrification in the *industry sector*. The industrial processes are very diversified, requiring different decarbonisation approaches. Some of these processes can be electrified more easily and cheaply than others. Towards 2040 we expect that industry processes that require low to medium heat will be largely covered by electricity rather than fossil fuel energy sources. In thermal processes at high temperatures we see that hydrogen from electrolysis or natural gas with carbon capture and storage (CCS) might play a key role. Hydrogen is discussed further in the next chapter. Overall, we expect that 35 per cent of the industry's energy demand will be covered by electricity in 2040, up from 26 per cent today.

Within *buildings* power consumption will increase in heating, cooling, and electrical appliances. The electricity share in this sector increases from 31 per cent today to 46 per cent by 2040.

Global power demand growth is met by renewable energy

Due to rapid deployment of intermittent renewables, around 70 per cent of power generation will be covered by renewable sources by 2040 in the Low Emissions Scenario. Solar and wind power accounts for 50 per cent of production. In 2040 solar power will generate more electricity than wind and be the largest source of power generation. In 2040 nearly 30 per cent of power generation will be generated from solar power, while over 20 per cent will be generated from wind. There are three main explanations for this. First and foremost, solar PV is a relatively simple technology that can be installed almost everywhere, while wind turbines are, to a greater extent, limited by the available space and size regulations. In addition, solar PV cells can be integrated into buildings with similar costs to alternative building materials, whilst wind turbines will always have a cost associated with raw materials.

Global power production towards 2040
TWh

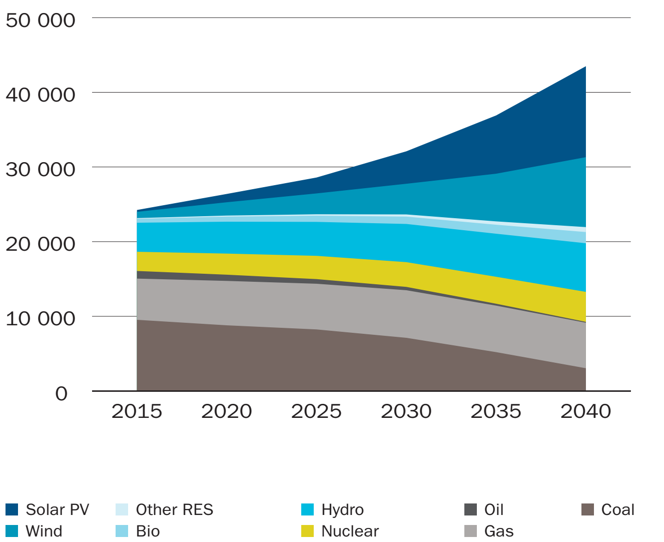
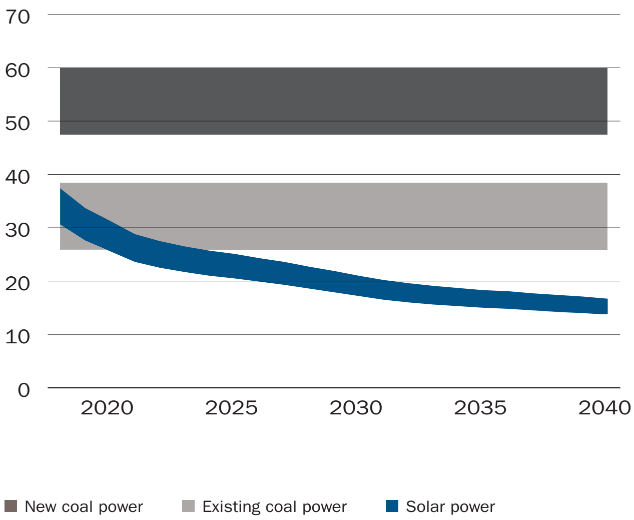


Figure 9. Growth of power demand towards 2040 in the Low Emissions Scenario by source (TWh).

Cost developments for solar PV and coal power
EUR/MWh

Cost developments for onshore wind and gas power
EUR/MWh



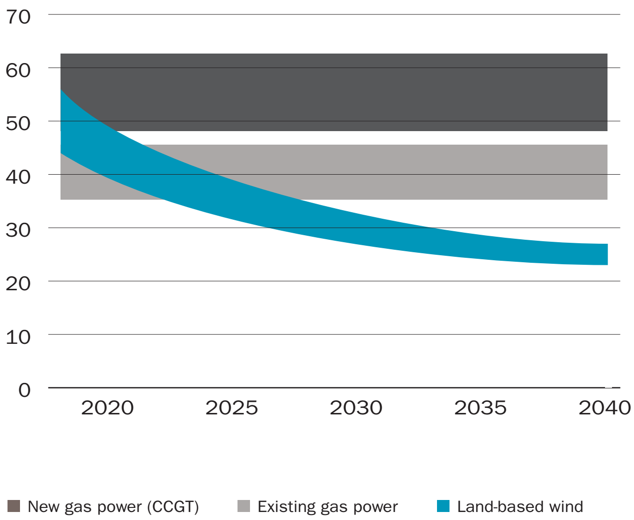


Figure 10. Illustration of cost declines in solar PV (utility-scale) in a sunny area to the left and cost declines for land-based wind power in locations with good wind resources to the right (EUR/MWh). Solar PV will become cheaper than existing coal power in a relatively short time. The graphs illustrate the possible outcomes around costs. Statkraft Low Emissions.

Lastly, solar PV can in combination with batteries in sunny areas provide a production profile that is stable and predictable throughout the day. Nevertheless, we expect that both technologies will be important going forward. Some places will still have better wind resources, and the two technologies will also supply different profiles into the power grid – depending on when the sun shines and when the wind blows.

Towards 2040, a large portion of power generation will occur in a more decentralised manner than it does today. In particular, solar power production can be constructed in a far more decentralised manner than traditional power plants. Globally, this is especially important in remote areas that can be electrified through distributed solutions. In addition, the reduction in battery costs presents opportunities for an increase in self-generation of electricity by both households and industry. New smart technologies facilitate more proactive and flexible demand profiles from consumers, and smart power grids will be able to handle this fragmented production and consumption.

Even with major changes, we will still not get a 100 per cent renewable energy sector by 2040

The costs of renewable energy are falling quickly enough to incentivise a rapid growth in installed capacity. However, the speed of growth will be limited by the challenge of solving the flexibility problems associated with the intermittent nature of solar and wind production.

If we are unable to solve the challenge of flexibility in a good way, renewable energy growth will be slowed. This will make it more difficult for the world to reach the two degree target, let alone holding the global temperature increase below 1.5 degrees. In the next chapter we address the need for flexibility in the power market and focus on what can offer this flexibility.

Figure 11. Solar PV is a relatively simple technology that can be installed almost everywhere, also integrated into buildings. Solar and wind power production can be constructed in a more decentralised manner than traditional power plants.

Powering a green future: **The need for flexibility increases in all markets**

Solar and wind power are changing the rules of the game for the power markets, as they differ from traditional generation such as coal and gas power in two important areas. Firstly, wind and solar power are intermittent. They produce electricity when the wind blows or the sun shines and therefore not always when the power is most needed. Secondly, contrary to fossil-fuel assets, their marginal costs of producing electricity are low, which drives down electricity prices. As the share of intermittent renewables increases so does the need for flexibility. This is evident in all markets we analyse and there are numerous technologies that are competing to provide this flexibility.

Our analyses show that the flexibility requirements increase for all time horizons, from a few seconds to periods that last several days and weeks. Flexibility solutions that cover short time periods will face high competition. There are fewer solutions that are able to cover the flexibility requirements over longer periods of time, such as entire days and weeks.

WHAT IS FLEXIBILITY IN A POWER SYSTEM:

Flexibility is the ability to make quick changes in production or consumption at any time to ensure balance in the power systems. This can be anything from an instantaneous change in power capacity over seconds and minutes (load regulation) to the balancing of power systems for extended periods, days or weeks, e.g. during periods of low wind.

The dynamics in the power markets are fundamentally changing with the increasing share of renewable energy

As the penetration rate of solar and wind power increases, more of the electricity will be produced during sunny or windy hours leading to lower prices. The revenues for solar and wind power owners will consequently be lower than the average market price. As more intermittent capacity is installed, the prices will fall further. This effect is referred to as the cannibalisation effect. Flexibility solutions can help reduce this effect and increase the profitability of renewables.

Both consumers and producers need the right incentives and price signals in order to provide flexibility solutions. It is in real time that the actual flexibility need and value is determined and so it is important to be able to sell and buy power in the market as close to real time as possible. It is also important that the variations in the power price are visible to everyone. A fixed daily power price, as an example, would not motivate consumers to adapt their electricity use by e.g. charging their electric vehicles at night when the power demand is lower.

It is not possible to know at present the optimal composition of the various flexibility solutions in the future. Therefore, it is important that these solutions can compete in the market on an equal footing, without a particular solution being supported separately. Nevertheless, we see today that many countries choose to preferentially facilitate certain types of flexibility solutions.

The value of flexible solutions is increasing in all power markets. There are different needs in different countries.

Towards 2040, the need for flexible solutions is expected to double for the Northwestern European countries [15]. At the same time, the national needs for flexibility vary in scope and type. European countries will be faced with completely different challenges and will therefore need different solutions (figure 12).

The large differences in flexibility needs between countries is due to very different physical power systems, level of interconnection and the share and type of renewables deployed.

Norway has the highest share of renewable in the power sector, the highest degree of electrification and has virtually zero CO_2 intensity in the power mix. On the other hand, Poland has a very different starting point with a high share of fossil fuel in its energy mix. There are also major differences when it comes to solar and wind resources. The wind resources in UK and Norway are on average significantly better than most other countries in Europe, and Spain is on top when it comes to solar resources.

[15] The following European countries: UK, Germany, Poland, France, Austria, Czech Republic, Netherlands, Belgium, Switzerland

	Share of electrification *(MWh per capita)*	Renewable share of power *(%, 2016)*	CO_2 intensity *(tCO_2/MWh, 2016)*
Norway	25	105	0
Sweden	14	65	0.1
UK	5	25	0.3
Germany	7	32	0.4
Poland	4	13	0.7
France	8	19	0.1
Spain	6	37	0.3

Figure 12. The starting point and challenges are unique to each of the European countries. Renewable share of power produced as a percentage of domestic consumption. Source: Eurostat, EEA

The technology mix in the north western European power production is changing

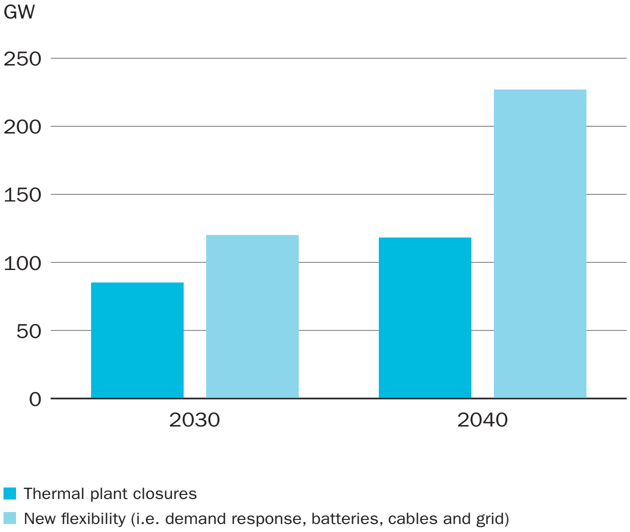


Figure 13. The phasing out of fossil fuel power generation and increase in new flexibility in Northwestern Europe (GW). Source: Statkraft analyses

A POWER MARKET IS NOT LIKE ANY OTHER MARKET

Electricity is similar to other commodities that are traded in markets such as metals, oil, and grains in several ways. However, the power market differs from the other commodity markets due to the following characteristics:

- Electricity is a perishable commodity and cannot be controlled in an easy and efficient way. Large volumes of electricity cannot be stored economically (at present) and the transmission of electricity must ensure a secure flow in the system at all time. Therefore, the cost and value of electricity varies depending on *location* and *time*.
- The need for electricity can vary abruptly over time. Some power plants can only change their production gradually and it may take several hours to restart, while other power plants may have to shut down abruptly for various reasons. Consumption and production of electricity must be in a continuous balance, otherwise there is a blackout risk. That is why the ability to shift production or demand at short notice, i.e., *flexibility properties*, has its own value.

When it comes to electricity, the power capacity (MW), energy (MWh), transmission capacity, and flexibility all have a value and can therefore be traded and priced in the various power markets, from several years in advance and right up to the delivery of power in the present (almost real time).

Towards 2040, we expect that most of the existing coal power plants in Northwestern Europe will shut down due to a combination of carbon prices, age, and regulations (fig. 12). By 2040 over 100 GW of fossil fired capacity will be phased out. At the same time, over 200 GW of new flexible capacity will be added to the power system.

Our analyses show that the share of renewable, intermittent power generation in the UK will increase from around 20 per cent today to around 70 per cent by 2040. During the same period, we expect that the need for flexible solutions will triple. In Germany we also expect that wind and solar power will account for around 70 per cent of the annual power generation by 2040, whilst the need for flexible solutions increases by a quarter from today. The Nordic countries differ from most other countries and regions. With flexible, renewable hydropower as the basis, and 74 per cent renewable share of power generation today (around 100 per cent in Norway), the need for new flexibility in the Nordic countries will be lower.

Various flexibility needs require different solutions

	Changes in demand	Gas	Coal	Hydro	Demand response	Storage (batteries)	Cables/ grid	Nuclear
Balancing (0 -1 hours)	↗	✓		✓	✓	✓	✓	
Intraday (1 – 24 hours)	↗	✓	(✓)	✓	✓	✓	✓	
Intraweek (1 – 7 days)	↗	✓	✓	✓			✓	(✓)
Base load (>1 week)	↘	(✓)	✓	✓				✓

Figure 14. All types of flexibility will increase, while the need for base load will be reduced in the markets we analyse. Source: Statkraft

The need for flexibility solutions can be divided into three types based on the time duration (figure 14):

1. Short-term flexibility within the hour («balancing»),
2. Short-term flexibility within a 24 hour period («intraday») and
3. Long-term flexibility within several days and sometimes weeks («intraweek»).

Fig. 15. Solar resources around the equator mean that we see high growth in intermittent solar power along with short-term flexibility solutions in this area. Further north and south the solar resources decline, but wind and hydropower resources are generally better. The combination of these technologies will provide flexible, renewable power.

The need for short-term flexibility within a 24 hours period (intraday) will increase the most in countries with more solar power. Long-term flexibility (intraweek) will increase most in countries with a lot of wind power. There are significant differences between wind and solar power profiles. Solar power variations are quite predictable during the 24 hours and over the season, while wind power is more unpredictable. Periods with high wind typically build up over time and can last for several days and even weeks. The solar power profile is shorter and can rapidly shift from zero to maximum production. Our analyses suggest that in Germany and the UK, with good wind resources, the flexibility within weeks (intraweek) can make up around two-thirds of the total flexibility requirements by 2040. In India with a lot of solar power, our analyses show that over 80 per cent of the flexibility requirements by 2040 could be short-term flexibility (intraday) within a 24 hour period.

When different types of flexibility compete with each other, the price volatility is reduced. This leads to lower profitability for all flexibility providers. The more flexibility that enters the market, the lower the marginal income for the flexibility providers.

Within short-term flexibility there are many solutions, and strong competition is expected between these. Hydropower, coal power, gas power, battery storage, smart electric vehicle charging, and other types of consumer responses, as well as cables and networks will be able to cover the intraday need for flexibility. We expect that all short-term flexibility solutions will have to compete with batteries; they will set a price ceiling for short-term flexibility.

Today, it is mainly coal and gas power plants providing long-term flexibility solutions. In areas with sufficient resource potential, hydropower can provide both short and long-term flexibility. Other solutions, such as longer demand response from industry, hydrogen and cables, are still currently small in volume. At the same time, the need for available flexible capacity in the most stressed hours remains. Expanding the power capacity of hydropower will be one of the most economically attractive options to cover long-term flexibility needs.

As figure 16 illustrates, there will be entire weeks in Germany where all demand is covered solely by intermittent renewable power in 2040. But there will be other entire weeks with little wind, where around 70 per cent of the demand will have to be covered by other, more flexible sources. Due to the strong need for long-term flexibility in Germany, our analyses suggest that cables, coal and gas power plants will still account for a significant portion of the flexibility solutions in 2040. However, it is worth noting that power generation and emissions from coal and gas plants will be significantly lower than today with the limited running hours, which will negatively affect their profitability.

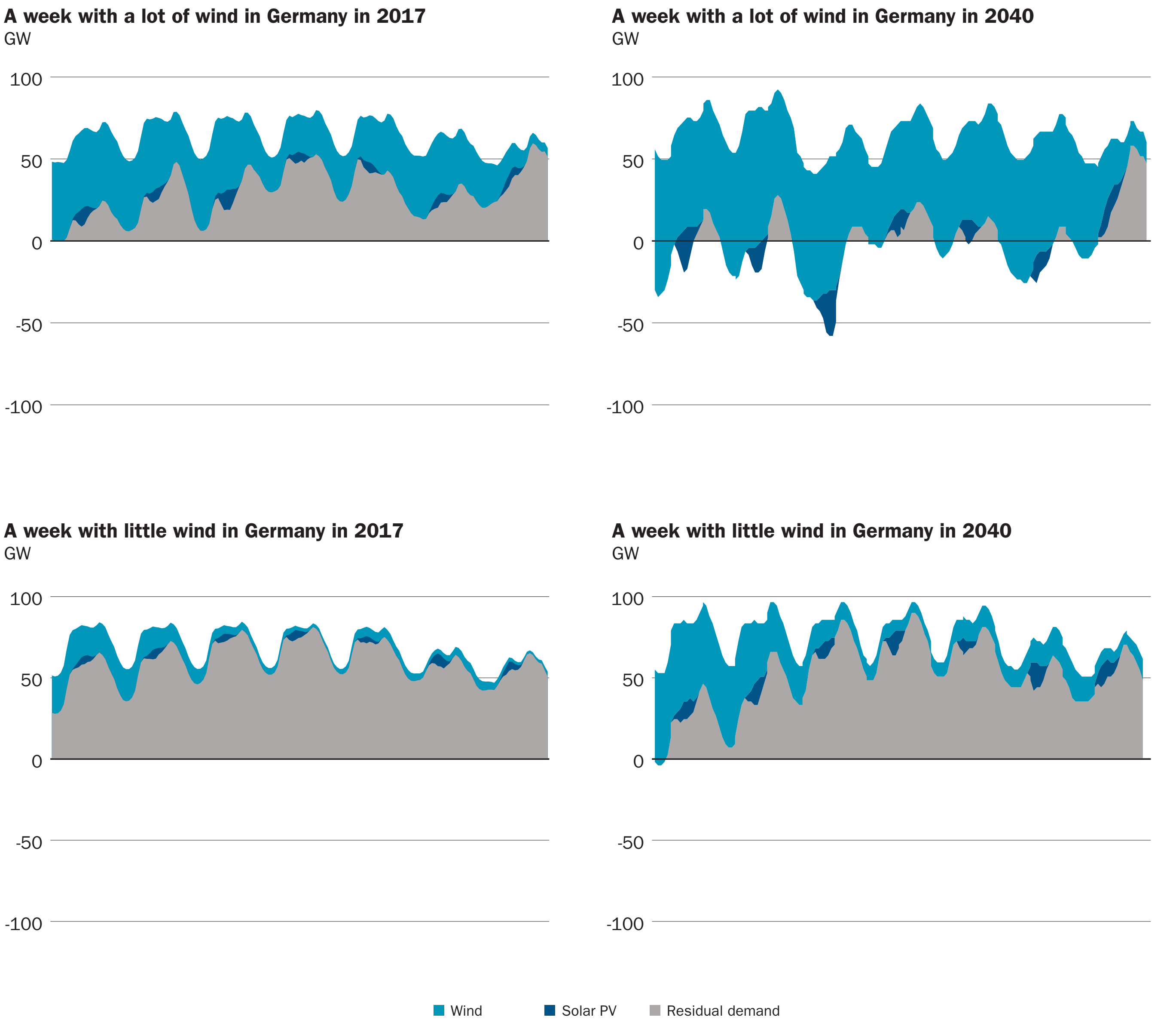


Figure 16. Illustration of how increased renewable share in the power mix changes the need for other types of generation from today until 2040 in Germany. Source: Statkraft analyses

Flexibility solutions
duration and marginal costs

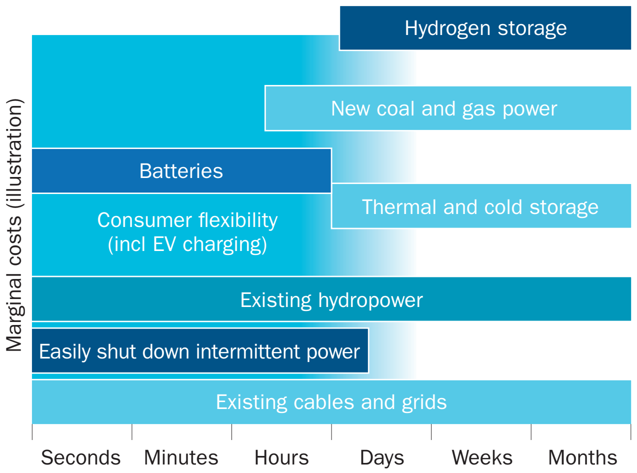


Figure 17. Illustration of marginal costs for various flexibility solutions which cover various flexibility needs. Statkraft analysis.

Numerous technologies and solutions will provide flexibility

Flexible hydropower can quickly change production and simultaneously have low start and stop costs. This makes hydropower well suited for a future power system with more intermittent power. Hydropower with reservoirs can provide short-term flexibility within an hour, as well as long-term flexibility over days, weeks and seasons. Hydropower plants with well-regulated reservoirs and high installed capacity will be important to cover the increasing flexibility needs.

A power system such as in the Nordic market, based on renewable, flexible hydropower has a unique ability to handle large variations in other renewable power sources such as wind and solar power. Hydropower has played and still plays an important role in keeping price fluctuations low in Norway and Sweden. The complementary profiles for inflow and wind make hydropower and wind power a good mix. The Nordic power system can also contribute with long term flexibility solutions in neighboring countries given sufficient cross-country interconnections. These countries can thereby bring more intermittent renewable power into their power systems while still preserving high security of supply. During periods of high winds, the power will go from countries in Europe to the Nordic countries, and during periods of low wind the power will go back from the Nordic countries to Europe.

Cables and grids increase access to flexible solutions

Cables and grids play an important role in flattening out imbalances between areas and countries. They also cover the need for both short- and long-term flexibility. Increased amounts of solar PV and wind leads to more weather-dependent power generation. It then becomes even more important to have physical interconnections and strong cooperation between countries. Integrated power markets can benefit from the differences in the power systems and can increase access to flexible solutions. If there is an area with a high share of wind power and an area

Figure 18. Renewable and flexible hydropower is important for covering the needs of both short- and long-term flexibility. Photo: Statkraft

Figure 19. Cables and grids are important flexibility solutions. Photo: Getty Images/RuudMorijn

with large hydropower reservoirs, the two areas will function more optimally if they are linked together in a common grid. Integrated power markets will make the transition to a fully renewable power sector more cost efficient and will reduce the need to use fossil fuels as back-up when there is no sun or wind. Physical infrastructure and close cooperation between countries are therefore high on the agenda in Europe.

Batteries and other energy storage technologies

In addition to hydropower, other technologies that store energy include different types of batteries, thermal storage, pumped-storage power plants, and hydrogen storage. *Battery technologies* are becoming increasingly cheaper. The Low Emissions Scenario expects a 75 per cent reduction in Li-Ion battery cell costs by 2040, primarily driven by the automotive industry (see figure 7). Cost developments vary for different types of batteries. Batteries can provide short-term flexibility in balancing power markets and can in some cases reduce the need for new investments in the power grid. As an example, batteries can be used as frequency support for grid operators, as fast chargers for cars where there is a weak grid, to even out intermittent sun and wind production and to store solar power for use in evening hours.

Today's batteries are not suitable for longer imbalances that last more than around four hours. At the same time there is a great deal of research and development underway to improve energy density, lifetime, efficiency, and to reduce costs and material usage in batteries.

Hydrogen may have a significant role in the future energy systems. An advantage of hydrogen is that its storage capacity is significantly higher than that of batteries. There are two options for the production of hydrogen without greenhouse gas emissions: From electricity using electrolysis and from natural gas with carbon capture and storage (CCS). The first option is called «green hydrogen» and the second «blue hydrogen». Future energy systems will most likely consist of both sources, depending on the available natural resources, infrastructure and location of the demand. Hydrogen can be used across energy sectors, thereby coupling the different sectors closer together, e.g. in heavy road transport, marine transport, and in industry as a reducing agent, fuel, or chemical component. Especially in the industry sector, there are a number of processes with few other options for decarbonisation than to use green or blue hydrogen. One drawback with using hydrogen as a flexibility provider in electricity systems is the 60-70 per cent energy loss when converting electricity to hydrogen and back to electricity. In comparison, there is about 15 per cent loss in a battery. In some cases, electricity to hydrogen to electricity may still be practical and economic, despite the energy loss. For example in isolated locations and small islands without grid capacity. We expect that hydrogen demand within transport and industry sectors will be the driving force for increased hydrogen production. However, the power sector may benefit from a more readily available and cheaper supply of hydrogen allowing for greater use as a flexibility provider in the future.

Great potential in consumer flexibility

Consumers can reduce their consumption during periods of high demand and increase their consumption during periods of low demand. Reducing and shifting consumption is referred to as consumer flexibility. This will contribute to a more even load on the system. Since the maximum load (i.e. the period with the highest demand) determines the dimension of the physical power grid, a more even load will utilise the grid better, and in some cases reduce the need for grid upgrades.

There are various forms of consumer flexibility. With smart technologies, consumers can control the use of electricity for heating, cooling, ventilation, and electrical appliances in buildings. In the future, more consumers will be both producers and consumers of electricity («prosumers»). Within heating there is great potential for flexibility as the production and storage of heat can be optimised based on power price levels. Electric boilers can increase their electricity consumption in periods when the share of intermittent power generation is high and power prices are low. Cogeneration (CHP) plants can stop producing electricity as a bi-product when the power price becomes lower than their marginal cost. Charging of electric vehicles can be shifted to periods of low demand with smart chargers ensuring the car is sufficiently charged before the next time it will be driven. The expected growth in electric passenger vehicles means that charging at an aggregated level has a major potential as a flexibility solution.

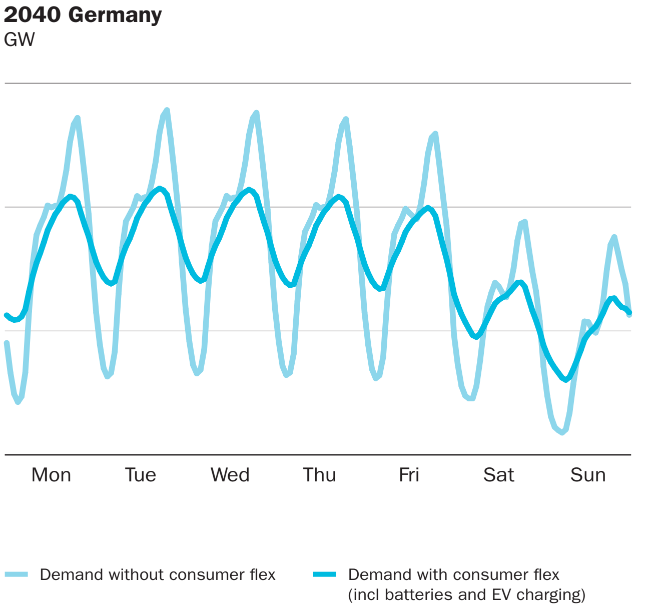


Figure 20. Consumer flexibility contributes to even out the load in the power systems by increasing consumption in periods of low demand and reducing consumption in periods of high demand within a 24 hour period (GW). Smart electric vehicle charging represents a major potential. Source: Statkraft analyses

FLEXIBILITY SOLUTIONS ARE MADE POSSIBLE BY DIGITAL TECHNOLOGY AND SMART SYSTEMS

Digital solutions with real time communications, sensors, and control systems enable and facilitate flexibility for both the consumer and producer. Digital solutions will help to optimise all parts of the power system and the interaction between them. This includes, among other things, operation and maintenance of power plants, grids and cables, power trading, and consumption. Digital solutions will for example contribute to automatic electric vehicles charging when it is most beneficial for the power system, as long as the vehicle is ready the next time it is needed. Improved interaction between the heating and power sectors will be possible through smart solutions. For example, a house can be heated by electricity when it is windy, and from gas when there is no wind. Ventilation and heating systems in buildings can automatically respond to electricity prices. Both consumer and production flexibility often consist of numerous small units. There are benefits of pooling smaller units together, for example by using an aggregator that can participate in the markets and better manage and optimise larger systems.

Electrification of the transport and heating sectors is therefore an important flexibility solution in the power systems. By providing flexibility to the power system, these sectors will facilitate an increased share of intermittent renewable energy and consequently faster decarbonisation of the power sector.

Flexibility in other power production plants

Improvements in technology and optimisation of running profiles will increase the utilisation of the flexibility potential in existing power generation. Existing *coal and gas power plants* are running more and more flexibly, and even *nuclear power plants* can respond to variations to a larger extent than previously believed. Coal and nuclear power plants will make up a smaller share of the production mix. New, highly flexible power plants like gas engines and open cycle gas turbines will be able to ensure security of supply during the hours of highest demand.

Wind and solar power production varies naturally with the prevailing weather conditions. Nevertheless, these plants also offer some flexibility. Wind and solar plant operators may decide to produce less in windy and sunny periods if this pays off economically. Even though these producers have low variable operating costs, the costs are not zero. The main reason that we get zero and even negative power prices during some hours in some markets at present, is the current support schemes for renewable energy in many countries where producers are not exposed to market prices. For older wind farms no longer receiving subsidies, it will often be more profitable to stop the turbines when prices are very low. This can reduce maintenance and grid costs and increase turbine lifespan.

A world with clean and cheap energy

Rapidly falling wind and solar costs are steering the world towards cleaner and cheaper energy. Improved economics of renewables will drive this energy transition forward, whilst policy and regulation will continue to play an important role in shaping the speed and nature of the change.

A cleaner power supply makes electrification an effective way to reduce emissions throughout the economy. Political ambitions and steep reductions in battery costs have already kick-started electrification of the transport sector. There is also significant potential to further electrify industry and buildings sectors. Increased use of electricity as an energy-carrier leads to energy efficiency gains, reduced local air pollution and not least lower global CO_2 emissions.

The fundamental changes to the way we produce and use electricity will also impact the demand for fossil fuels.
Oil demand will fall and coal's role in the energy mix will be halved. Increasing the share of renewables, which are produced locally, will be an important route for many countries towards reducing dependence on fossil imports.

Providing flexibility in the power market will become more important over time as the share of intermittent renewable power increases. There will be a need for different types of solutions that will vary significantly based on national circumstances.

Numerous solutions, from batteries to demand-side response, cables and grids, will compete to provide short-term flexibility. There are, however, limited technologies and solutions that can provide long-term flexibility. Since gas and coal emit greenhouse gases, it is expected that their role will diminish. Emission-free hydrogen can be a part of the solution in the longer term, but it is too early to tell what the potential here will be. This is where hydropower is in a unique position as one of the few renewable technologies that offer both short- and long-term flexibility.

It is impossible to say now what the optimal mix of technologies and solutions in the power sector will be going forward. Enabling flexibility through well-functioning power markets will be important to drive forward the transition to renewables in a cost-effective way. Countries will benefit from more closely integrated power systems and sectors to increase access to flexible solutions. Both consumers and producers also need the right incentives with power prices that reflect emission costs and the actual demand in the power system at any given time. This can enable a rapid renewable deployment and electrification towards 2040, resulting in a cleaner energy world consistent with a 2 degree pathway.

Sectors	Statkraft Low Emissions Scenario (2018)	IEA New Policies Scenario (2017)	IRENA REmap (2018) [16]	DNV GL Energy Transition Outlook (2017)
Average annual growth in primary energy demand 2015-40	0.5%	1.0%	-0.1% (to 2050)	-0.1% (to 2050)
Transport sector				
Oil share (final, Mtoe, 2040)	70%	81%	33% (2050)	n/a
% Electric vehicle (EV+PHEV) share of new vehicle sales	77% by 2040	13% by 2030	n/a	100% (by 2050)
Power sector (Annual average growth, TWh, 2015-2040):				
Demand	2.4%	1.9%	2.0%	2.5% [16]
Wind power	8%	6.7%	9.0%	10% [16]
Solar power	15%	10.7%	11.3%	14% [16]
Hydropower	2.1%	1.9%	1.1%	2% [16]
Fossil fuel share in power sector (TWh, 2040)	21%	50%	18%	9% (by 2050)
Oil consumption: annual average growth 2015-40	-0.8%	0.4%	n/a	0% (to 2050)
Gas consumption: annual average growth 2015-40	0.6%	1.5%	n/a	-1.4% (to 2050)
Coal consumption: annual average growth 2015-40	-2.6%	0.1%	n/a	-3.7% (to 2050)
Global energy-related CO_2 emissions ($GtCO_2$) by 2040	23.4	35.6	15.0	16.9 (by 2050)

Table 1. The assumptions in the Statkraft scenario compared to IEA, DNV GL, and IRENA [17].

[16] Power sector annual growth for IRENA and DNV GL forecast runs to 2050.

[17] The scenarios are based on different assumptions and are therefore not directly comparable. Both IEA and DNV GL scenarios are their reference scenarios. Statkraft Low Emissions Scenario is a technologically optimistic-realistic scenario.

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