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Flexibility Solutions for High-Renewable Energy Systems

Germany

BloombergNEF

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Foreword

Decarbonising the power system is imperative if we want to bring carbon emissions to a sustainable level. The last decade we have made important steps forward, increasing the share of renewables in the European power system significantly while bringing down the cost of renewable energy. This is only the beginning – dramatic growth in the share of renewable power generation capacity will be necessary in the future.

A key challenge is to integrate a large and growing share of intermittent power generation from wind and solar plants into the power system. This study shows that it is possible – stronger connections to the Nordic hydropower system, demand side flexibility, battery solutions and smart charging of EVs can play together, reducing the need for keeping fossil fuel capacity as a backup, thereby bringing down both costs and emissions.

For Statkraft, as the largest generator of renewables in Europe, it is interesting to see that Nordic hydropower reservoirs can play an important role for decarbonisation of the European power systems, together with other flexibility solutions. This is consistent with our own analyses – confirming that a global renewables share of 70 percent is possible by 2040 if we let modern solutions for flexibility and market design allow cheap renewables to replace more expensive fossil solutions.

Henrik Sætness, SVP Strategy & Analyses, Statkraft AS

The relentless advance of solar and wind energy technologies are driving us inexorably towards an electricity system dominated by variable renewable power generation. Combined with the expected growth in electric mobility, we are now in the midst of an energy transition which will massively lower carbon emissions and improve air quality. However, this opportunity will be appreciably limited unless energy markets are designed and regulated in a way that unlocks the full value of flexibility in the electric system.

Eaton is delighted to be co-sponsoring a new, wide-ranging study by BloombergNEF, which makes a compelling economic case for a wide variety of solutions to address the flexibility challenge faced by two countries – Germany and the UK – who are both at the forefront of the energy transition. This report is a follow up on BloombergNEF's Beyond the Tipping Point study from last year, which explained that much of the energy transition will occur in less than a decade, thus engendering a need for increased flexibility. The time is already upon us to prepare and start investing in the technologies, services, and modifications that can enable our energy system to cope with the dramatic shift in how we generate and use electricity. We expect that the findings of this report will help spur both industry and government across Europe to take the steps needed to prepare their grids for a high renewable future, and at the same time, fully realise the enormous commercial and environmental opportunities such actions will create.

Cyrille Brisson, Vice President of Sales and Marketing for the EMEA region, Eaton

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Section 1. Executive summary

8%

More expensive power system by 2040 without new sources of flexibility

26%

Net emissions reduction by 2040 from a higher uptake of flexibly-charged electric vehicles

11%

Lower emissions if batteries become even cheaper or additional interconnections to the Nordics are built

New forms of flexibility are key to an affordable, renewables-led power system. Without energy storage, smart-charging electric vehicles, demand response and interconnectors, the German energy transition risks proceeding on a suboptimal path, with an expensive power system reliant on fossil backup and oversized renewable capacity.

This report, authored by BloombergNEF in partnership with Statkraft and Eaton, explores the newer possibilities for solving the power system flexibility challenge in Germany: energy storage, demand response, flexible electric vehicle charging and interconnections to Nordic hydro. (We are simultaneously publishing a similar report for the U.K. Although both countries are on a path to higher renewable penetrations, our analysis has led to different conclusions about the role of flexibility in each nation's transition.)

Building on BloombergNEF's flagship forecast for the global electricity system, the New Energy Outlook (NEO), this report develops scenarios to explore alternative futures for the power system, depending on how each flexibility technology might develop in the coming years. It uses BNEF's proprietary New Energy Outlook modelling tools, meaning that every scenario is, for the given assumptions, a least-cost optimal solution. Each scenario starts with different underlying assumptions about what each technology can provide, and/or at what cost.

The report analyses seven scenarios (Figure 1). They are all variants of the NEO base case, which was published in June 2018 and contains some degree of demand response, flexible EV charging and a relatively large volume of batteries.

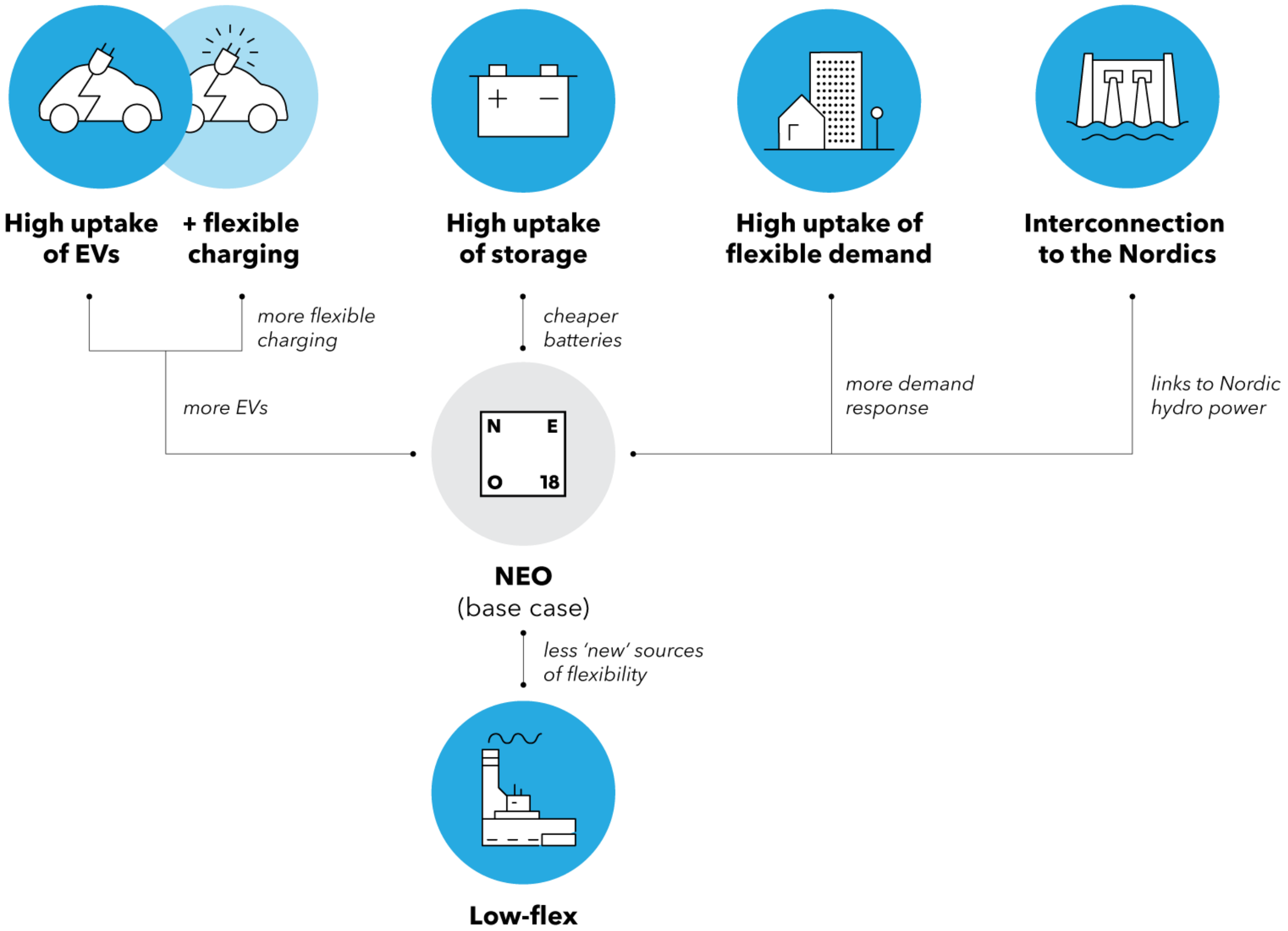
The low-flex scenario considers the consequences if these technologies are substantially held back, whereas each of the other scenarios introduces or accelerates a single 'new' source of flexibility. The accelerating factors that we consider include a 2040 internal combustion engine ban, the increased popularity of flexible EV charging, faster battery cost declines, increased demand response uptake and the introduction of several interconnection lines to the Nordics and their substantial hydro resources.

The main conclusions are that:

- **Flexibility can support renewables… or coal**
  - **Renewables** by adding value to generation either by shifting excess demand to periods of high renewable generation, or by storing the excess renewable generation for periods of high demand.
  - **Coal** by making better use of the existing renewable assets, smoothing the peaks and troughs in generation and enabling coal-fired power stations to run at higher capacity factors. This means it is cheaper to run inexpensive coal plants more, than to build new renewable capacity.
  - In short, flexible technologies help integrate inflexible ones.
- **In Germany, adding flexibility supports coal through 2030** – whether it takes the form of more flexible EVs, more storage or more interconnection. Over this timeframe, these new

forms of flexibility act to support inflexible but cheap lignite in particular, rather than to increase renewable generation and reduce emissions.

Figure 1: The scenarios



Source: BloombergNEF

- **But by 2040, flexibility makes possible greater renewable penetration and emissions savings.** By this point, coal's contribution to the system is smaller and renewables are even cheaper. The added flexibility now enables more cheap renewable capacity to be built and integrated effectively, pushing fossil generation out and reducing emissions substantially. In 2040, a lack of substantial 'new' flexibility (our low-flex scenario) would require 19% more fossil backup capacity and make the system 8% more expensive. This is because it requires a wasteful approach, with major renewable capacity overbuild (and high curtailment levels). It's worth noting that through 2030 this low-flex approach disrupts baseload lignite generation and actually reduces emissions.
- **These challenging findings are not due to a problem with batteries, EVs, demand response or interconnectors – cheap coal is the culprit.** In our modelling, it is the economics and capacity mix that determine whether flexibility acts to support renewables or conventional power plants. Germany still produces large amounts of power from cheap lignite being burned in relatively modern, efficient plants. With lignite's abundance in the system and

low price, anything that makes its operating environment more stable enables greater burning of the fuel. To reduce emissions, coal needs to be phased out.

- **New sources of flexibility are needed in the near term.** Across all scenarios, there is a need for battery storage from the early 2020s onwards. In Germany, by 2025, the storage capacity required by the system in our base case NEO scenario is 5.1GW, and ranges across scenarios from 2.2GW to 6.0GW. Allowing the aggregation of storage to provide grid services as well as rewarding utilities and distribution companies for contracting distributed energy resources are key to supporting these new sources of flexibility that will enable the transition to a high renewable energy system.
- **To decarbonise, Germany needs to address existing coal generation and not only invest in renewables, flexibility and interconnection**. In our NEO base case, German power sector emissions remain relatively high, just 25% down on 2030, despite a functioning EU ETS producing carbon prices of 30 euros or higher per metric ton. This highlights coal and lignite’s unassailable position in the market and the need for this to be addressed, whether through a greater focus on carbon pricing, or a phase-out plan. Adding renewables and then integrating these with flexible technologies will not be sufficient.
- **Even with Germany’s coal-heavy power, adding EVs reduces transport emissions.** Even if internal combustion engine vehicles are phased out by 2040, EVs do not ‘break’ the power generation system. System costs are hardly raised while net emissions – after accounting for avoided tailpipe emissions – come down 18% by 2040, or 26% if more of those vehicles charge flexibly in response to market conditions. High levels of flexible charging also make possible greater renewable penetration and reduce fossil backup capacity by 22% by 2040. However, impacts on the transmission and distribution network are likely to be significant.
- **Adding more energy storage also reduces emissions by 2040,** by enabling the German power system to support more renewables. The New Energy Outlook base case already includes a significant share of energy storage, but in a scenario where storage gets even cheaper, emissions come down a further 11% by 2040 as result of cheaper batteries. This happens as 3% more renewable power is integrated into the grid and fossil backup capacity reduced by 3%.
- **Interconnection with the Nordics provides a formidable source of flexibility for decades.** They reduce power sector emissions 11% by 2040, while also making the system cheaper and reducing its reliance on fossil fuel backup capacity. The interconnectors’ role changes over the forecast, shifting in the earlier years from providing imports, especially during shoulder months, to absorbing excess renewable generation, especially in the summer, later on. This means the interconnectors start to behave more like a seasonal storage battery, resulting in a reduction in fossil backup capacity required and highlighting the versatility of interconnecting to a market with a high degree of clean flexibility.
- **Adding more flexible demand reduces the need for battery investment.** Adding demand response beyond what is already available in the NEO base-case scenario does not have much impact in terms of emissions, the fossil backup required or the share of renewable generation. However, it halves battery capacity by 2040, indicating that it could be very effective at replacing batteries in their role of integrating higher shares of renewable power.

The scenarios nominally explore technology outcomes, but they can also be seen through a policy lens: policymakers and regulators can help to bring them about by creating favourable market environments for flexibility sources. Favourable market conditions for flexibility might include:

- Introduction of dynamic power pricing (potentially mandatory) for energy customers – and for electric vehicle charging
- Establishment of frameworks for distribution network operators to share the value of flexibility
- Greater incentives or compensation for rapid-responding resources within capacity and ancillary markets
- Shortening of the trading and settlement interval in the wholesale power market
- Expansion of market access for energy storage and demand-side resources – including aggregated resources – and lower barriers for participation, across capacity, energy and balancing markets
- Equal treatment of interconnectors/overseas resources within these markets.

Table 1: Summary of scenario outcomes in 2030

Scenario	System cost	Emissions	Fossil capacity as share of peak demand	Renewable share of generation
NEO (base case)	40.8 EURm/TWh	144 MtCO2	81%	75%
Relative change vs NEO				
Low-flex	0%	-3%	-1%	1%
High uptake of EVs	1%	-7%	-1%	2%
High uptake of EVs and flexible charging	1%	1%	-5%	-1%
High uptake of storage	0%	4%	-2%	-1%
High uptake of flexible demand	1%	-1%	0%	0%
Interconnection to the Nordics	-1%	0%	-4%	0%

Table 2: Summary of scenario outcomes in 2040

Scenario	System cost	Emissions	Fossil capacity as share of peak demand	Renewable share of generation
NEO (base case)	48.6 EURm/TWh	109 MtCO2	56%	83%
Relative change vs NEO				
Low-flex	8%	-15%	19%	3%
High uptake of EVs	1%	-18%	-7%	2%
High uptake of EVs and flexible charging	-1%	-26%	-22%	4%
High uptake of storage	0%	-11%	-3%	3%
High uptake of flexible demand	0%	2%	-1%	0%
Interconnection to the Nordics	-2%	-11%	-4%	3%

Source: BloombergNEF. Note: Colour scales differ between columns, but in all cases green is desirable. Emissions for EV scenarios include a negative contribution from emissions displaced in the oil sector; net imports included in renewable share of generation.

Section 2. Introduction

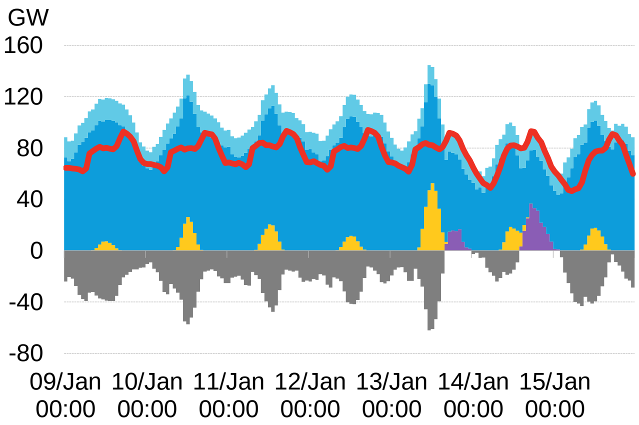
Germany has made good progress on its energy transition, with renewables achieving 36% penetration in 2017 – but much more still needs to be done to meet long-term climate goals.

Thanks to the rapidly falling costs of wind and solar energy, it is now possible to envision a future German power system dominated by renewables. BloombergNEF's *New Energy Outlook* forecasts that a least-cost scenario would lead to 83% renewable generation in the power system by 2040, with most of the gains made before 2030.

Operating such a system will require significant new sources of flexibility. Last year, BNEF, Eaton and REA published *Beyond the Tipping Point: Flexibility Gaps in Future High-Renewable Energy Systems in the U.K., Germany and Nordics.* That report identified the following key issues:

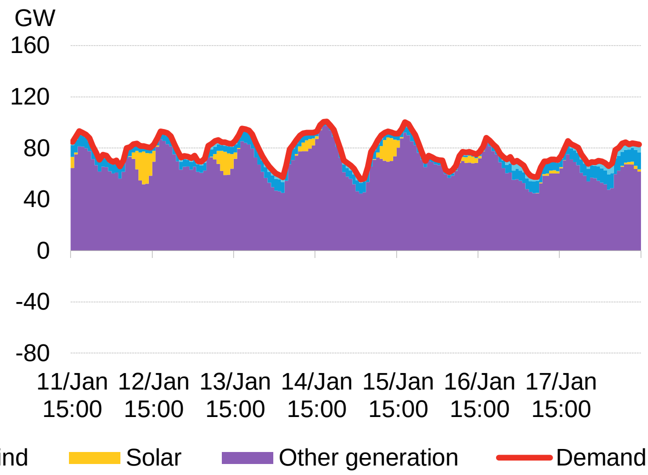
- In 2030 and 2040, variable renewables meet more demand, more of the time – impacting other generators and creating opportunities for flexibility, including storage, flexible demand and interconnectors. In 2040, these resources contribute to more than 65% of hourly demand in Germany for over half of the year.
- With increasing frequency, there will be entire days and even weeks when total renewable energy supply exceeds demand, but also days, weeks and even months when the majority of demand must be met by other sources
- System volatility increases markedly– by 2040, the highest German hourly ramps are 38GW up and 34GW down, equivalent to around 40% of Germany's entire generation fleet turning on or off in one hour. This creates a very challenging environment for 'baseload' technologies such as nuclear, coal and lignite, and increases the need for flexible, fast-acting technologies.

Figure 2: Highest wind and solar output week in the Germany, 2040



Source: BloombergNEF

Figure 3: Lowest wind and solar output week in Germany, 2040



Source: BloombergNEF

In short, that report gave a shape and size to the flexibility challenge facing the power sector as it decarbonises. Thanks to technology innovation in areas such as energy storage and demand response, there is a growing set of options available to address these challenges – but there is also a degree of uncertainty around costs and availability of these technologies, and their implications for the system.

This report, authored by BNEF in partnership with Statkraft and Eaton, explores the newer possibilities for solving the flexibility challenge: energy storage, demand response, flexible electric vehicle charging and interconnections to Nordic hydro.

In reality, all of these technologies (as well as traditional peaking plant) will play a role, so we have adopted a scenario-based approach to explore different assumptions about each technology, and how they might impact the overall trajectory of energy transition. Each of our scenarios solves the flexibility challenge, but in different ways. Some rely more on thermal plants, while others build more renewable energy or rely on the new technologies.

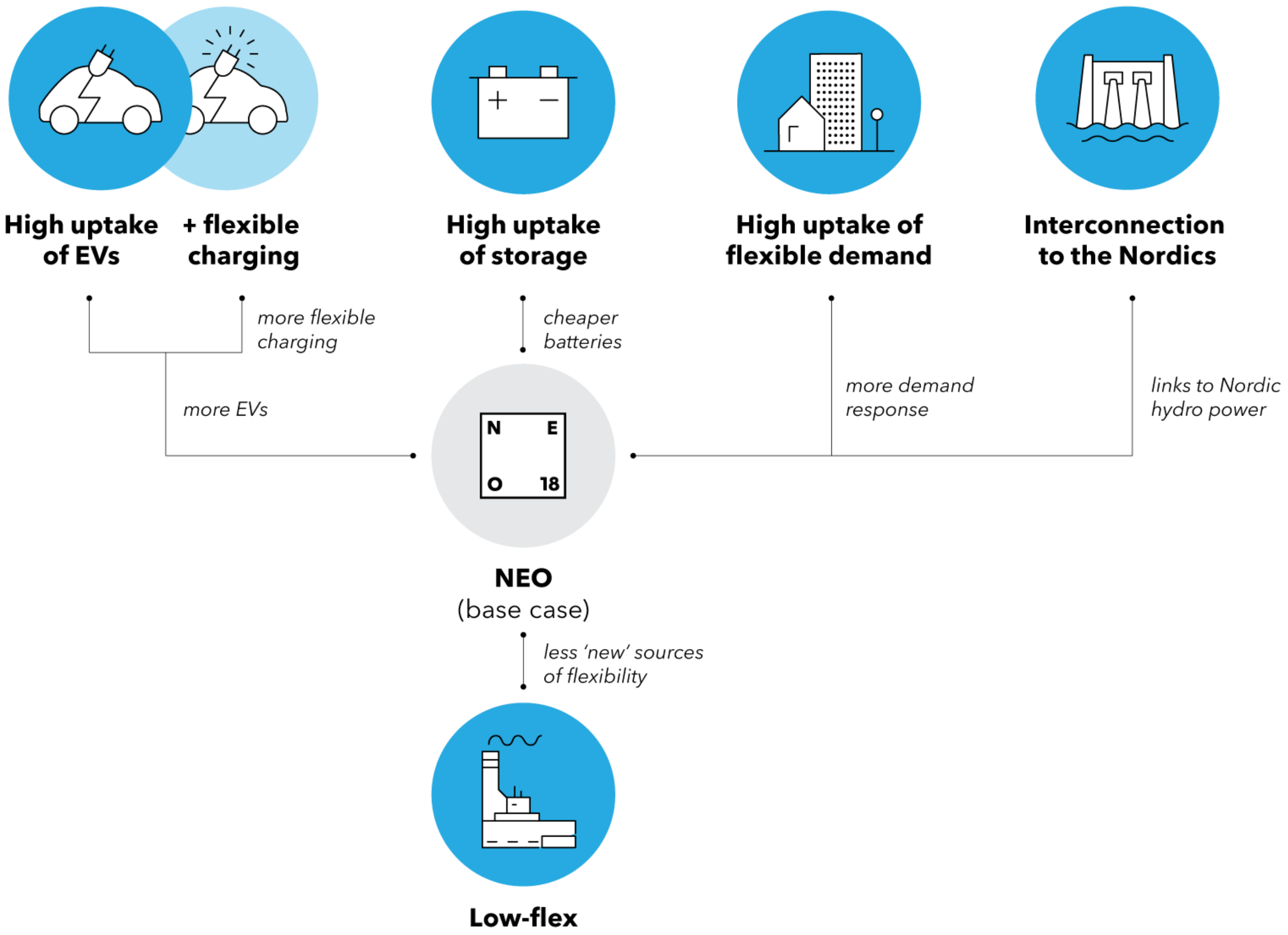
The modelling was undertaken using BNEF's proprietary New Energy Outlook modelling tools, meaning that every scenario is, in its own way, a least-cost optimal solution. What differs across scenarios is the underlying assumptions about what each technology can provide, and/or at what cost. In this way, we are able to explore alternative futures for the power system, depending on how each flexibility technology might develop in the coming years.

Of course, technology is not the only issue. Policy and regulatory approaches to enabling the addition of flexibility are critical, and the scenarios can also be seen in this light. Where demand response, storage, interconnectors and flexible EV charging are successful in our scenarios, it can be inferred that market designs had to be favourable to their introduction and adoption.

The scenarios in summary:

- **New Energy Outlook (NEO base case):** this scenario is the Germany forecast from our 2018 *New Energy Outlook*, published earlier this year. The cost and availability assumptions on demand response, energy storage and electric vehicles are consistent with BNEF's house view (but interconnectors are not modelled). Demand response grows, battery storage becomes cheaper, and electric vehicle charging is partially flexible (ie, some of it can be moved to different hours to take advantage of cheap renewable power).
- **Low-flex:** this scenario looks at the consequences of a future with almost no new sources of flexibility. Here we assume that storage costs remain higher, demand inelastic and demand response unattractive. Electric vehicles are charged with no regard for grid conditions or power prices.
- **High uptake of electric vehicles:** this scenario is consistent with a ban on the sale of internal combustion vehicles by 2040. The result is an accelerated rate of adoption of electric vehicles, leading to higher power demand.
- **High uptake of electric vehicles and flexible charging:** considers the same uptake of electric vehicles as in the previous scenario, but with greater adoption of flexible charging.
- **High uptake of storage:** this scenario explores a future where battery costs fall faster than expected.
- **High uptake of flexible demand:** assumes a more widespread uptake of flexible demand as a result of successful market design and aligned incentives for demand shifting.
- **Interconnection to the Nordics:** analyses the benefits of interconnecting the German power market with Nord Pool, and in particular the hydro resources in Norway.

Figure 4: The scenarios



Source: BloombergNEF

All of the scenarios are variants of the NEO base case – in other words, the storage scenario *only* differs from the NEO base case in its assumptions about storage. The interconnector scenario *only* differs from the NEO case in that it includes interconnectors – and so on. So when comparing scenarios, it is best to compare each one to the NEO case.

The remainder of this report first explains the NEO base case, and then explains each of the other scenarios in turn, how they differ from NEO, and what implications to draw from them. Each scenario is evaluated in terms of emissions, cost and security of supply. We then end with a set of summary conclusions across all scenarios.

Section 3. NEO scenario

Our base scenario is based on the Germany forecast within BNEF's *New Energy Outlook 2018*. The *New Energy Outlook*, or NEO for short, is our annual long-term analysis of the future of energy.

3.1. A word on NEO

NEO forecasts the global electricity system with a focus on technologies that are driving change in markets and business models across the sector, including solar PV, onshore and offshore wind, and batteries. In addition, we put special focus on changing electricity demand, electric vehicles, air-conditioning, and the growing role of consumers.

For the near term, we make market projections based on an assessment of policy drivers and on BloombergNEF's proprietary project database, which provides a detailed insight into planned new build, retrofits and retirements, by country and sector. For the medium to long term, our results emerge from a least-cost optimisation exercise, driven by the cost of building different power generation technologies to meet projected peak and average demand, taking into account weather extremes, country by country.

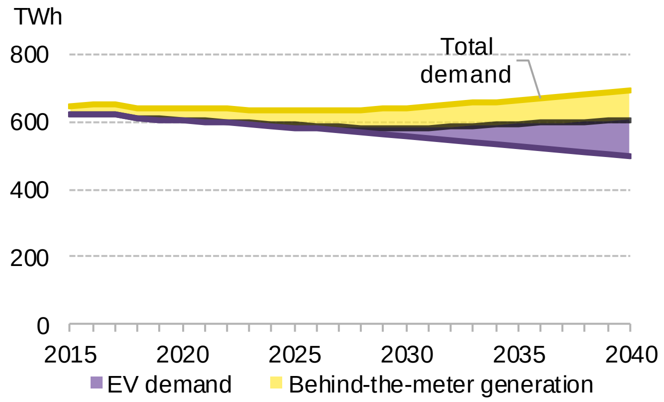
3.2. Germany forecast

In the NEO base case, Germany sees rapid change in its electricity mix to 2025, with coal and gas generation falling to 29%, nuclear being phased out and renewables topping 70% of generation. However, the transition then slows. Battery deployment helps renewables reach higher penetration but, in the absence of policy intervention, cheap lignite is likely to remain in place. Note that we do not assume a specific coal phase-out plan in Germany.

By 2040, Germany is running on 68% wind and solar, and 83% renewables in total. Some 16% of German electricity demand is from EVs and 25% of system capacity is small-scale PV and storage, which sits behind the meter with business and households.

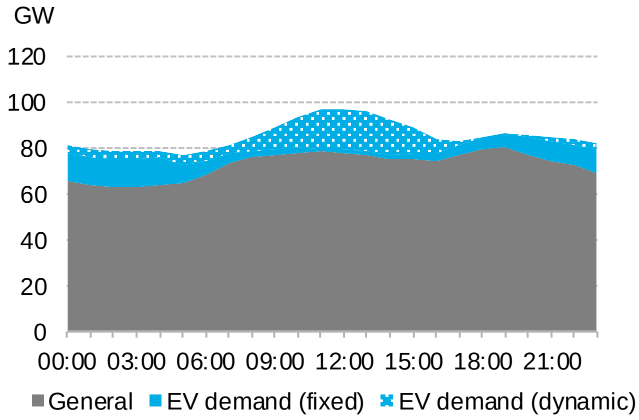
Germany's power demand grows by 7% over 2017-40, to 692TWh, driven by the increasing penetration of electric vehicles (EVs). By as early as 2035, EV charging makes up 10% of total electricity demand, with the share increasing to 26% in 2040 (Figure 5).

Figure 5: Electricity demand breakdown



Source: BloombergNEF

Figure 6: Daily hourly demand profile, 2040



Source: BloombergNEF

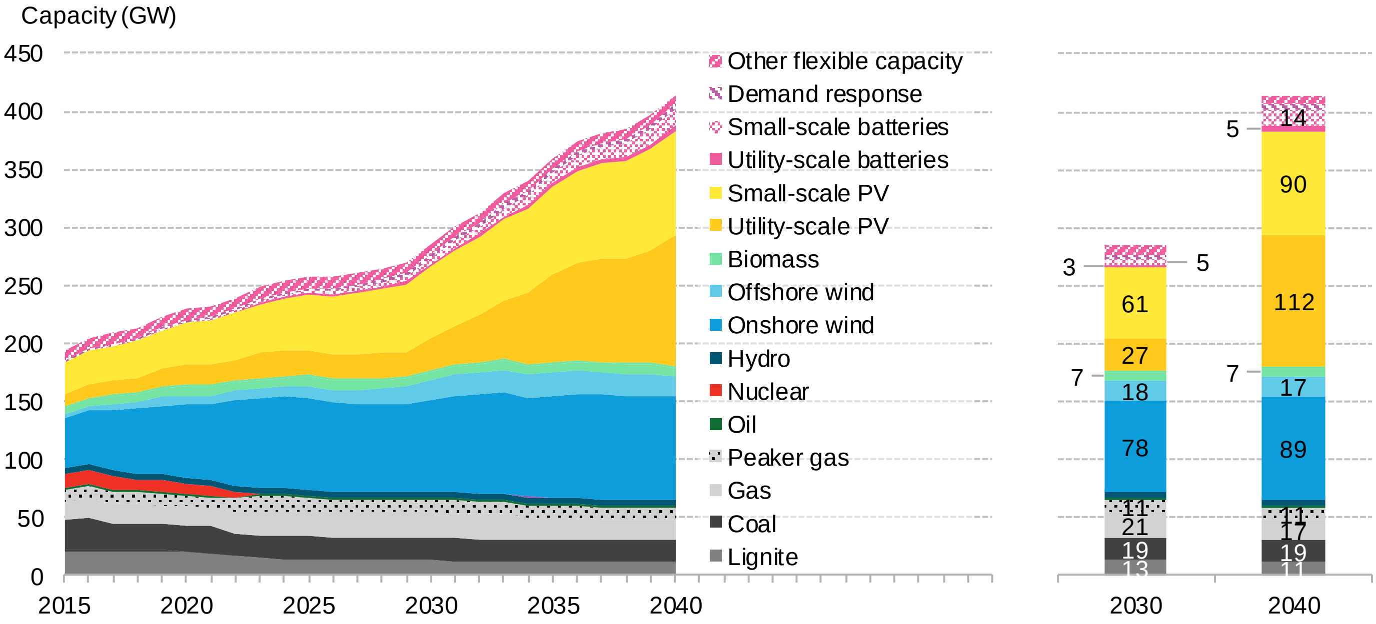
Generation capacity

Generating capacity grows 110% to 438GW by 2040 (Figure 7). A staggering 76% of the 229GW added is solar PV. By 2024, there is more PV in Germany than conventional fossil fuels capacity and by 2029, solar becomes the largest segment of the power system, with 33% of the capacity mix.

Wind energy does not play as big a role in Germany as it does in other European countries, like the U.K. Over 2017-40, Germany adds 93GW of wind, and over three quarters of that is onshore. At the same time, we expect 40GW of wind turbines to be decommissioned as older farms reach their end of life. Combined onshore and offshore wind capacity peaks in 2038 at 115GW, falling to 110GW by 2040. Onshore wind turbine improvements, which allow the same generation with fewer megawatts, contribute to this fall in capacity.

Despite strong renewables growth, fossil-fired generation is much more resilient in Germany than in other parts of Europe. German fossil fuel capacity shrinks by only 14% over 2017-40, to 62GW. This is in stark contrast to Europe as a whole, where fossil fuels shrink by 42% in GW terms. German coal plants are hard to displace and as a result, most stay online until 2040. This means that if Germany wants to rid itself of its coal, it will have to do so through policy action.

Figure 7: Evolution of Germany's generating capacity in NEO



Source: BloombergNEF

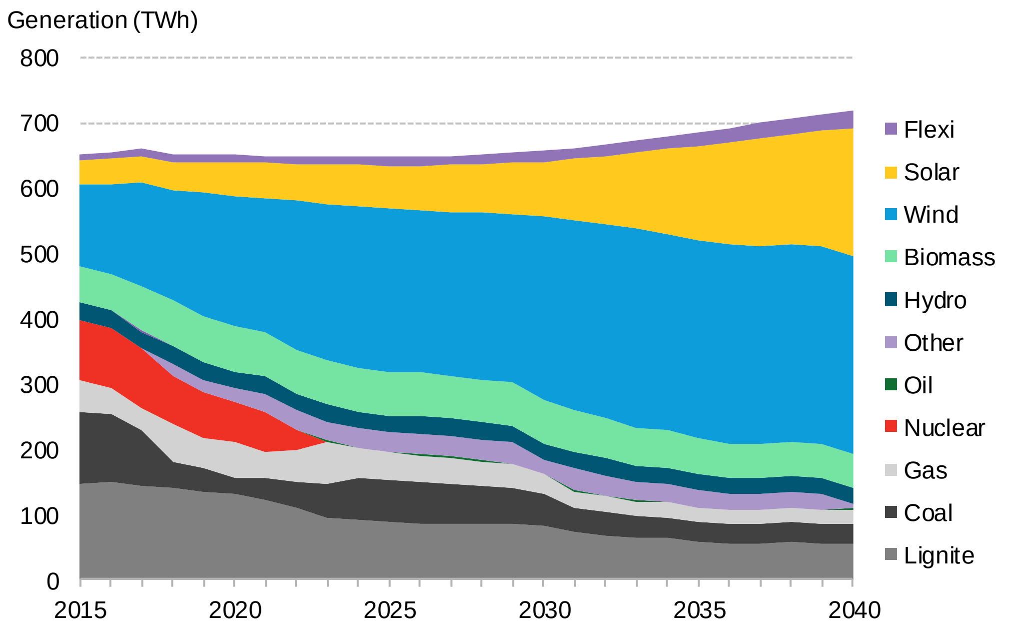
Power generation mix

The German generation mix changes most dramatically over the next eight years. Coal and gas generation drops by 29%, from over a third of the mix in 2017 to under a quarter by 2025. Over this same short period, nuclear is set to be phased out, and onshore wind generation is up 75% to 240TWh. By 2021, onshore wind overtakes coal as the number one source of electricity in Germany. The share of renewables in generation by 2025 is at 71%.

After 2025, the growth of wind and solar generation in Germany slows, from an average increase of 8% per year over 2017-25, to 5% per year over 2026-40. The 2025-30 slowdown in renewables growth is a common theme in our European country-level forecasts. It appears that getting to 70% wind and solar penetration without additional flexibility is relatively easy. But going beyond that requires batteries, and these become competitive for a wider range of time periods in the 2030s, unlocking solar's further potential.

By 2040, Germany is running on 68% wind and solar, and 83% renewables overall. Still, the country has a 17% share of fossil fuel generation, three times the European average. This mainly reflects cheap lignite generation which, despite contracting by 34%, still produces 56TWh per year in 2040.

Figure 8: Evolution of Germany's generation mix in NEO

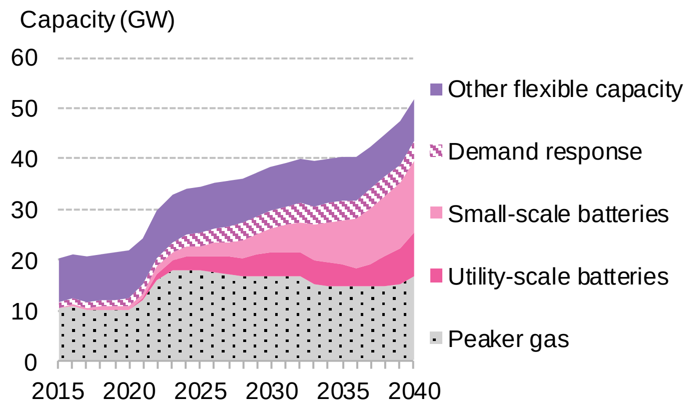


Source: BloombergNEF

Flexibility

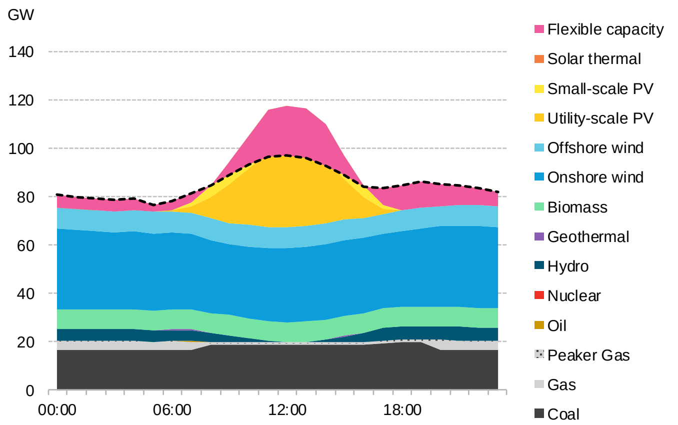
In order to absorb all of this renewable energy, Germany grows its flexible capacity 2.5 times over 2017-40, to 52GW, or 12% of the total (Figure 9). Small-scale batteries are central to this growth, making up 44% of the 31GW added, particularly after 2035. The country also adds 7GW of peaking gas plants, mainly to replace coal and gas capacity lost in the latter part of the outlook. This flexible capacity helps Germany absorb high levels of midday solar generation, apportioning it to other times of the day, when it is better used.

Figure 9: Cumulative new flexible capacity



Source: BloombergNEF Note: Flexible EV demand not shown

Figure 10: Daily dispatch, 2040



Source: BloombergNEF

Small-scale PV is already 15% of total capacity in Germany. This is the result of policies and tariffs aimed at helping the economics of small-scale installations. Germany is set to remain the

European leader in distributed capacity, adding 60GW of small-scale PV to 2040, when nearly a quarter of total capacity in Germany is behind the meter.

Figure 11 through Figure 13 show how flexible technologies contribute to meet demand and integrate renewables during weeks with different levels of renewable generation in 2040:

- During a 'low-renewable' output week (Figure 11), there are over four consecutive days when large fossil generators are needed to meet demand. Batteries also charge and discharge on an almost daily basis, to shift renewable generation from high to low output hours. Peaking gas comes online during such low-renewable output hours to meet demand, and it even contributes to charge batteries when renewables and large fossil generators cannot do it on their own. Charging batteries is critical, as meeting evening peaks relies on it.

Figure 11: Week with low renewable output in 2040

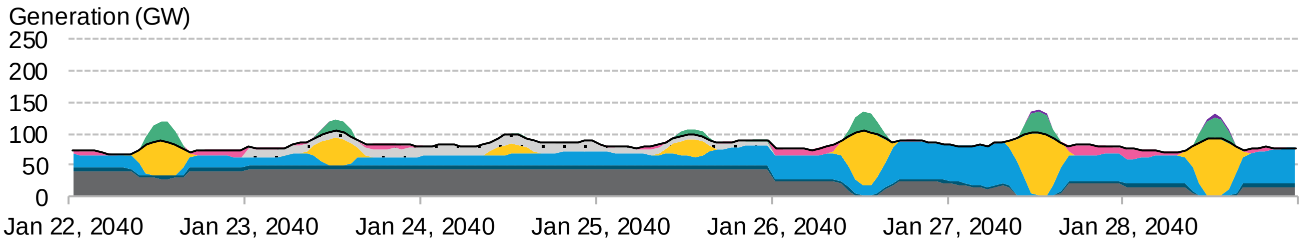


Figure 12: Week with median renewable output in 2040

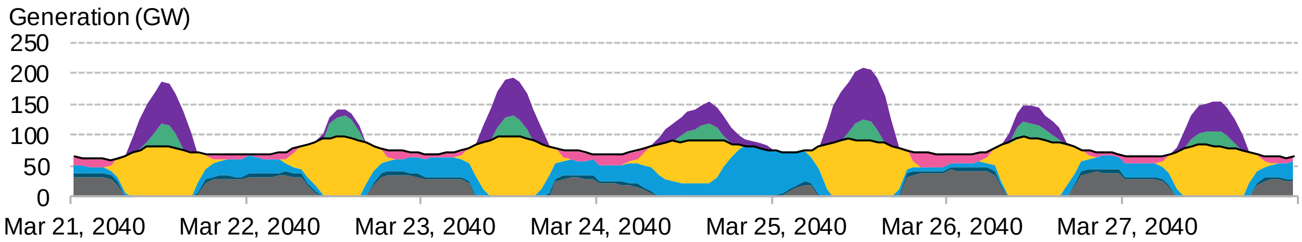
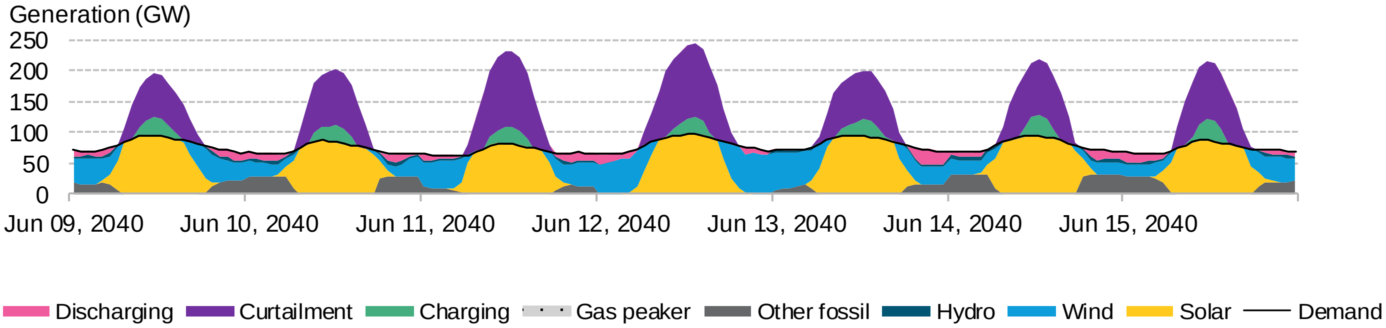


Figure 13: Week with high renewable output in 2040



Source: BloombergNEF

- On a more typical week (Figure 12), we observe higher levels of wind and solar generation, which leaves little room for continuous fossil generation. Coal and gas come on and off sporadically, while batteries are used at some point on a daily basis, charging during the day and discharging when the sun sets.
- In weeks where renewable output is at its highest (Figure 13), nearly all demand is met by renewables, leaving little room for fossil generation. Storage plays an important role, to help meet demand during the few hours when there is not enough low-carbon generation, but it does little to reduce curtailment during the middle of the day, when combined wind and solar generation is at its highest.

3.3. Implications

Under our NEO base case, Germany's power sector emissions are set to fall 50% between 2017 and 2033. This is progress, but it is significantly slower than the European average, which achieves that reduction by 2027. By 2040, German emissions fall to 109MtCO_2, a 55% drop from 2017. By that point, Germany emits more than the rest of Europe combined as its lignite plants continue to run. This difficulty in cutting emissions beyond a certain point demonstrates the challenge in reaching fully decarbonised systems with just wind, solar and batteries – and without action to close legacy plants.

With that said, flexible resources such as energy storage, demand response and flexible EV charging play an important role in the NEO scenario. By 2040, there is a total of 23GW of battery storage, 4GW of demand response, and 55TWh of flexible EV demand that can be shifted to meet renewable production. The next section discusses the low-flex scenario, which highlights how different the outcomes would be if these sources of flexibility were unavailable.

Table 3: Key metrics for NEO scenario

Metric	units	2018	2030	2040
System cost	EURm/TWh	34.5	40.8	48.6
Emissions	MtCO2	221	144	109
Fossil capacity as share of peak demand	%	89%	81%	56%
Renewable share of generation	%	49%	75%	83%

Source: BloombergNEF

The system that NEO forecasts to 2040 is based on a least-cost optimization. The model builds the cheapest system that can meet demand at all times, but it does not ensure that each individual asset makes a return on market revenues. As such, for the NEO outlook to materialise would require careful market design and the right market-based price signals to maximise the value from new technologies. This would include frameworks for efficient investment in solar PV and both onshore and offshore wind, as well as market-based signals for energy storage and demand shifting.

3.4. Other scenarios

The next sections explore other scenarios for flexibility, and compare each of them to this NEO base case. It is worth keeping in mind when comparing scenarios that NEO represents a future in which there are significant flexible resources, in particular with a high volume of batteries and a large share of electric vehicles (50%) engaged in smart charging. This is why we present a low-flexibility scenario next for comparison, before showing the high-storage and other scenarios.

Section 4. Low-flex scenario: limited flexibility

In this scenario, we look at the consequences of a future with almost no new sources of flexibility, where storage costs remain higher, demand inelastic and demand response unattractive – either due to technical or regulatory reasons.

In recent years, variable renewables, namely wind and solar, have experienced cost reductions that have exceeded expectations. In this scenario, wind and solar continue to decline in cost as expected, but new barriers mean that demand response, flexible EV charging and energy storage are expensive or unavailable.

Like wind and solar, lithium-ion batteries have also experienced large cost reductions, but there is some uncertainty surrounding their future costs. If manufacturing does not scale up as quickly as expected, or if there are bottlenecks on critical materials such as lithium or cobalt, this could lead to higher battery pack prices than expected. Trade barriers, or an immature supply chain in Europe, could also lead to higher costs.

This scenario is also intended to explore the effects of suboptimal policy and regulatory frameworks. Poor market design decisions that introduce misaligned incentives could slow or stop the adoption of storage, demand response and flexible EV charging. For example, dynamic pricing or aggregation can encourage residential and business customers to invest in demand-side flexibility, such as small-scale storage or dynamic EV charging. Without these incentives, the German power system might not realise the potential of these technologies. Similarly, if power market and frequency response rules do not appropriately value new sources of flexibility, these technologies may not achieve scale.

EV charging patterns: what does bad look like?

Current EV charging is not very flexible: EVs charge mainly at home when owners return from work, and for the most part chargers do not respond to power price signals. As a consequence, EVs act as a fixed load that peaks around 6:00 or 7:00 PM – the same time when power demand is at its highest – increasing the stress on the system.

This can be avoided by distributing charging events throughout the day in response to price signals. However, to do so EVs need access to charging infrastructure for most of the day (not only in the evening). This implies additional investment in workplace and other destination chargers.

This scenario considers the impact on the system in a world where EV drivers are not able to access charging infrastructure outside their homes and thus charge mostly during the evenings, in an uncontrolled manner. What could make matters worse (which we do not explore here) is if rapid charging were to capture a large share of EV charging load. If left uncontrolled (and not supported by onsite storage, for example), this could lead to demand spikes that would drive up costs in the power system.

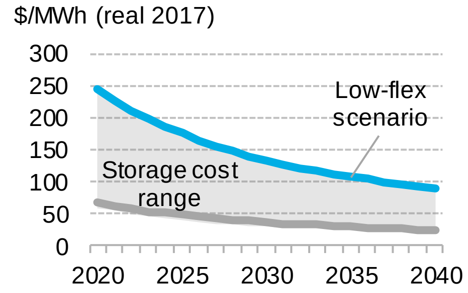
4.1. How this scenario differs from the NEO base case

Input assumptions

To model the low-flexibility scenario, we altered our input assumptions to make battery storage, demand response and EV charging less flexible, available or affordable:

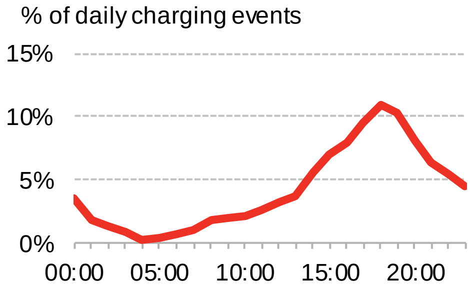
- For battery storage, we assumed a cost trajectory at the higher end of our range, giving a levelised cost of finance (LCOF)[1] about four times more expensive than the costs used in NEO (Figure 14). In contrast, NEO is quite bullish in terms of battery storage and assumes costs on the lower end of our cost range.
- We assume that there is no flexible charging for electric vehicles. Instead, they follow a fixed charging pattern that peaks during the evenings – specifically between 6:00 and 7:00 PM based on existing charging data (Figure 15). The vast majority – about 80% – of the fleet charges at home, while the remaining vehicles utilise some sort of public charging infrastructure. This assumption contrasts with our NEO scenario, which assumes 50% of the fleet charges flexibly by the early 2030s.

Figure 14: Storage levelised cost of finance



Source: BloombergNEF

Figure 15: EV charging profile



Source: BloombergNEF

- In addition to the battery storage costs and EV charging parameters, we assume that demand response remains at existing levels and does not play a significant role in this scenario.

Together, these assumptions are intended to reflect a future where new flexibility technologies are rendered unattractive, either due to technological reasons or due to sub-optimal power market design and regulatory approaches.

Outcomes

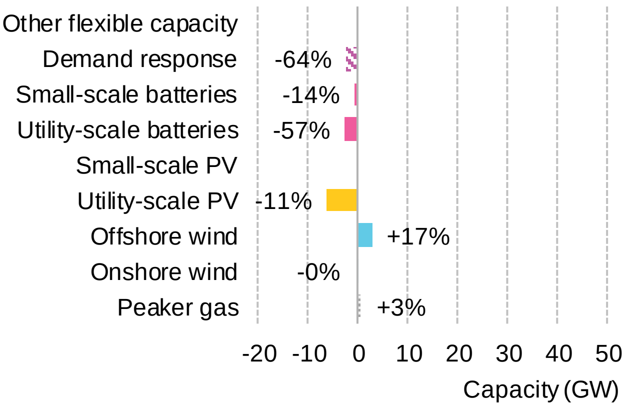
In a future where new flexibility technologies do not fulfil their potential, Germany's power system looks markedly different. The limited contribution of new sources of flexibility (batteries and demand response) means the system instead relies heavily on peaking gas. By 2030, the changes are not yet very noticeable, as the system in this scenario requires just 0.5GW (3%) more peaker gas capacity than the NEO base case. But there is 35% (3.3GW) less storage (Figure 16), which is a significant change.

By 2040, the system needs almost twice as much peaker gas capacity as the NEO base case, to make up for the lack of battery storage capacity, which is reduced by 28% (6.4GW) (Figure 17).

The lack of battery storage and demand response means that the most economical option is to build some 50GW of additional renewables capacity to meet demand during certain hours, even if this means curtailing renewable generation more frequently at other times. The result is somewhat counter-intuitive: removing or limiting new sources of flexibility, such as energy storage, has actually led to a higher adoption of renewables in this scenario.

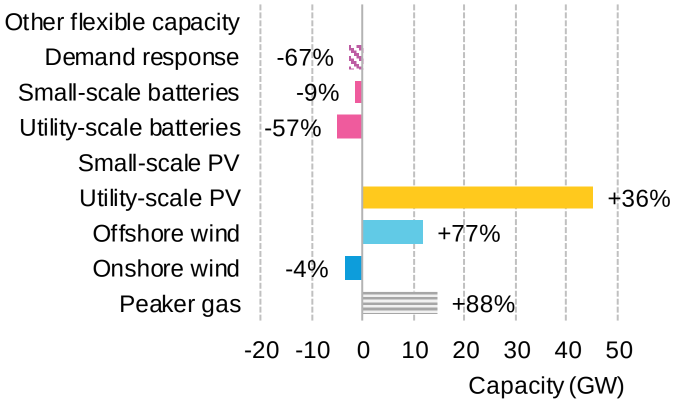
[1] The levelised cost of finance is the long term off-take price on a MWh-basis needed for a project to pay back its capital costs and hit the equity requirements of investors; it excludes variable costs such as fuel, carbon or charging costs in the case of batteries.

Figure 16: 2030 generation capacity change for low-flex scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 17: 2040 generation capacity change for low-flex scenario, versus NEO base case

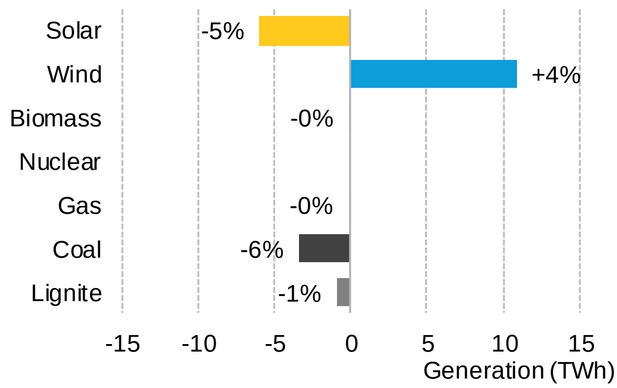


Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

The significant additions of wind and solar due to the lack of new sources of flexibility also impacts the generation mix. A small share of lignite and coal generation is replaced by wind in 2030, but by 2040, some 20-25% of lignite and coal generation is replaced by wind and solar. By 2040, flexible gas generation also grows, replaces biomass and becomes the main source of flexibility given less battery and demand response capacity. Again, the results are counter-intuitive: removing flexibility seems to help renewables, and hurt coal and lignite, in our analysis.

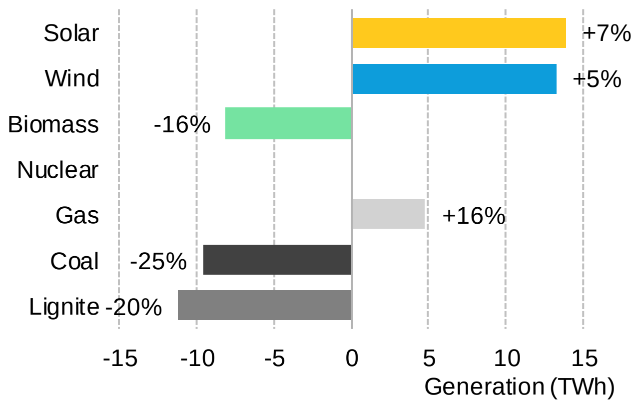
Although in 2040 wind and solar generation increase, the reduction in energy storage means growth in generation happens to a lesser degree than growth in capacity – a 77% growth in wind capacity translates to a meagre 5% increase in generation. In other words, more and more renewable generation is not utilised, as it cannot be accommodated with the system's remaining flexible resources.

Figure 18: 2030 power generation change for low-flex scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 19: 2040 power generation change for low-flex scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

4.2. Implications, benefits and drawbacks of this scenario

In all of our scenarios, the system has enough flexibility to maintain reliable operation – and this one is no different. However, without new sources of flexibility, this is achieved primarily by relying on additional peaker gas capacity and extra build of renewables.

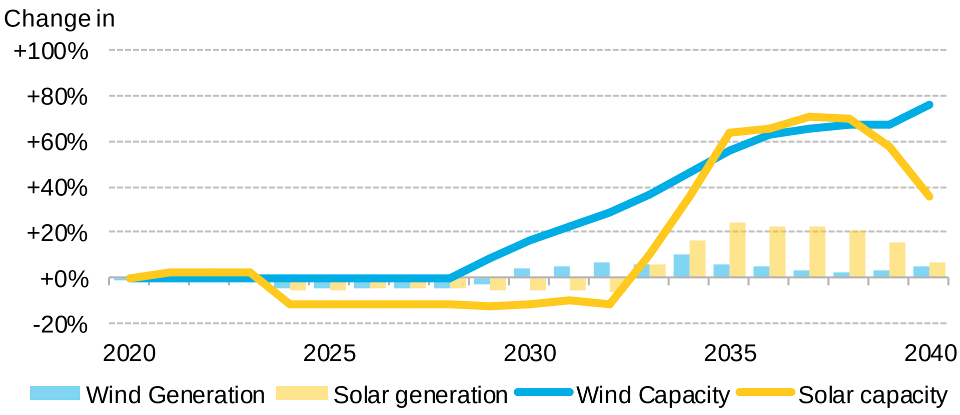
In 2030, the low-flex system is quite similar to NEO, and so are its costs. The latter are just 0.5% higher than the NEO base case, but by 2040 the difference in system costs increases significantly to 8% (Table 4).

The low-flex scenario is a costlier, and less efficient outcome for the German power system

Inflexible assets, such as renewables and lignite are underutilised as a result, and there is much more curtailment. Importantly, however, a lack of new flexibility does not halt the transition to a renewables-led system, as renewables are still cheap to build (even if they go underutilised). Even in a world where DR, storage and flexible EV charging fall short of their potential, renewables still achieve 85% penetration by 2040 (Table 4).

Figure 20 illustrates how wind and solar additions are changed in this scenario. Additional renewables capacity is required from 2028 onwards, but by the 2030s actual wind and solar production struggles to keep up with capacity, due to curtailment.

Figure 20: Growth in wind and solar capacity vs generation



Source: BloombergNEF

However, the most surprising result is that German carbon emissions are actually lower in this scenario: reducing new sources of flexibility has led to better emissions performance, not worse. This is in part because of the persistent presence of coal and lignite power plants throughout the forecast period. Like renewables, these generation sources are not very flexible, but they are inexpensive at the moment of production. This means that the removal of flexible demand and storage actually harms their prospects in the power market – so in both 2030 and 2040, coal and lignite produce less than in the NEO base case. Put another way, the growth of storage and flexible demand in the NEO scenario actually helped to boost the utilization of coal and lignite plants.

The reduction of battery storage and demand response also results in an oversized wind and solar park that contributes to the reduction in emissions of 3% in 2030 and 15% in 2040, compared with NEO (Table 4). In spite of all the extra capacity, the penetration of renewable generation does not increase significantly, rising by only 3% percent by 2040.

This scenario result is a challenging one: it shows that adding flexibility alone cannot meaningfully dent Germany's carbon emissions from coal and lignite – for this, policy action will be needed to retire these plants. In contrast, the same analysis for the U.K. (see separate report) showed that flexibility helps to reduce emissions by reducing reliance on gas – but this is only possible because of the U.K.'s coal phase-out from 2025 onwards.

Table 4: Key metrics for low-flex scenario

Metric	Units	2030	2030	2040	2040
		Value	Δ vs NEO	Value	Δ vs NEO
System cost	EURm/TWh	40.9	+0%	52.4	+8%
Emissions	$MtCO_2$	139.5	-3%	92.8	-15%
Fossil capacity as share of peak demand	%	80%	-1%	66%	+19%
Renewable share of generation	%	76%	+1%	85%	+3%

Source: BloombergNEF

Section 5. Scenario: high uptake of electric vehicles

In an effort to combat air pollution and climate change, countries around the world are incentivizing the uptake of electric vehicles, with some going as far as setting dates from which sales of new internal combustion engine vehicles will be banned.

In this scenario, we looked at the impact on the German power system from implementing such a ban by 2040. In it, we assume an accelerated rate of adoption of EVs, rising to 21% of the fleet in 2030 and 81% by 2040 (Figure 21).

Managing local grid constraints

Growing penetration of electric vehicles has the potential to cause problems for the physical network. Distribution system operators, already having to adapt to distributed generation, will have to manage higher peak load on increasingly constrained lines – this is especially true of EVs using fast chargers.

Solving this issue will be paramount to the widespread adoption of EVs. There are various solutions, ranging from the deployment of additional network capacity to making more efficient use of existing infrastructure – for example, via the deployment of demand response, smart charging and active network management.

Although there are various issues around it, bi-directional vehicle charging, also known as vehicle-to-grid (V2G), has the potential to provide the electricity system with a wide range of load shifting and balancing services.[2]

5.1. How this scenario differs from the NEO base case

Input assumptions

Using the same tools and methodology as in our Electric Vehicle Outlook,[3] we modelled the impact a ban on sales of new internal combustion engine (ICE) vehicles from 2040 would have on the makeup of the German fleet (Figure 21), This allowed us to estimate the additional electricity demand needed to power the increase in electric vehicles (Figure 22).

We assume the same level of flexible charging for electric vehicles as in NEO, as follows:

- 2018-2025: vehicles charge following a fixed pattern that favours charging overnight when vehicles are parked at home (Figure 23).
- 2025-2040: time-of-use charging is slowly implemented and vehicles increasingly charge flexibly, responding to conditions in the system. By 2035, about half the EV fleet has transitioned from fixed to flexible charging (Figure 24).

[2] Bloomberg subscribers can read more in *Vehicle-to-Grid: the Slow Roll from Demonstration to Commercial Projects* (web | terminal).

[3] Bloomberg subscribers can read more in our Electric Vehicle Outlook (web | terminal).

Figure 21: Vehicle fleet

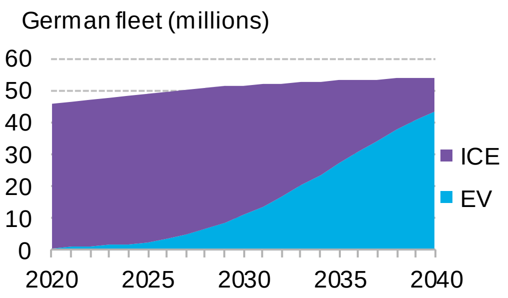


Figure 22: EV demand

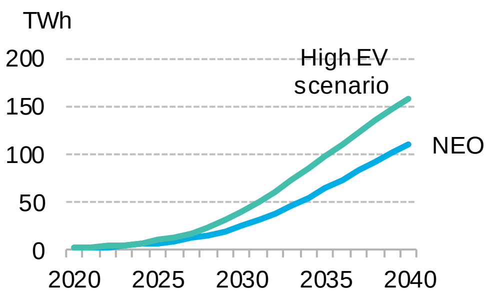


Figure 23: Fixed charging pattern

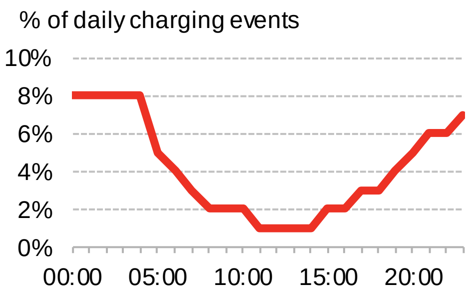
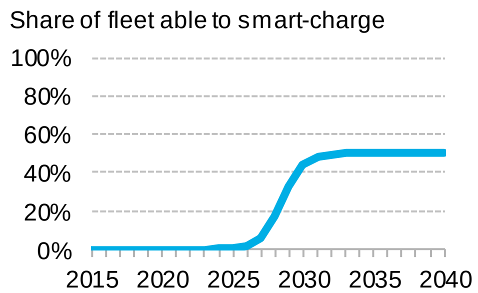


Figure 24: Penetration of flexible charging



Source: BloombergNEF

Outcomes

With more electric vehicles than in our base-case NEO scenario, additional generating capacity is needed to meet the extra power demand. This is in the form of wind and solar first of all, able to provide bulk electricity generation, as well as gas peakers and utility-scale battery storage to back this up and shift some of the excess renewable energy to more valuable times of the day. By 2030, these additions add up to about an extra 8.9GW of mostly wind capacity – an increase of 3% over NEO (Figure 25).

By 2040, additional demand is significantly higher and consequently the system adds around 78.8GW of capacity, or 18% more than in the NEO scenario (Figure 26). Notably, by this point, the economics of solar in Germany make it the most attractive technology. Consequently, by 2040, solar is added in large amounts – more than 40GW – to meet the additional EV demand. Extra onshore and offshore wind capacity is also built to help meet demand when the sun is not shining.

Figure 25: 2030 generation capacity change for high EV uptake scenario, versus NEO base case

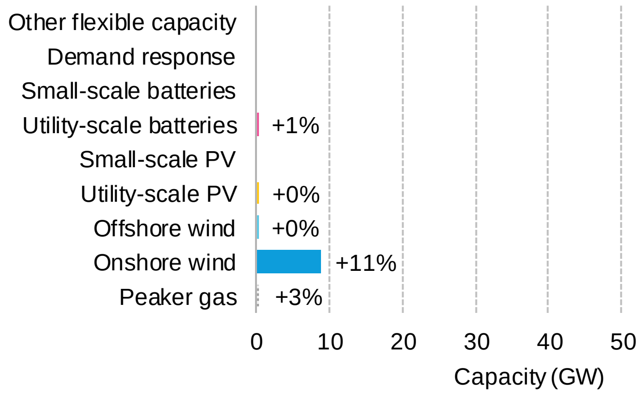
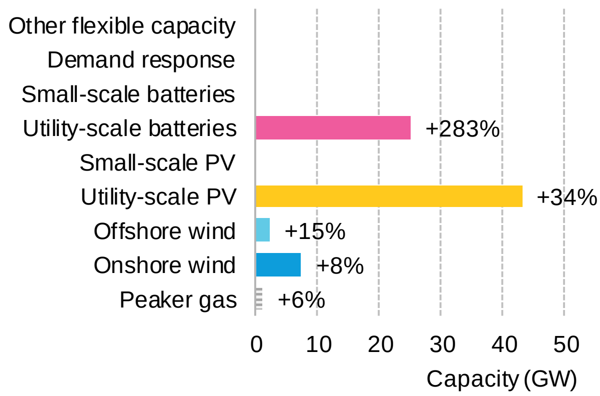


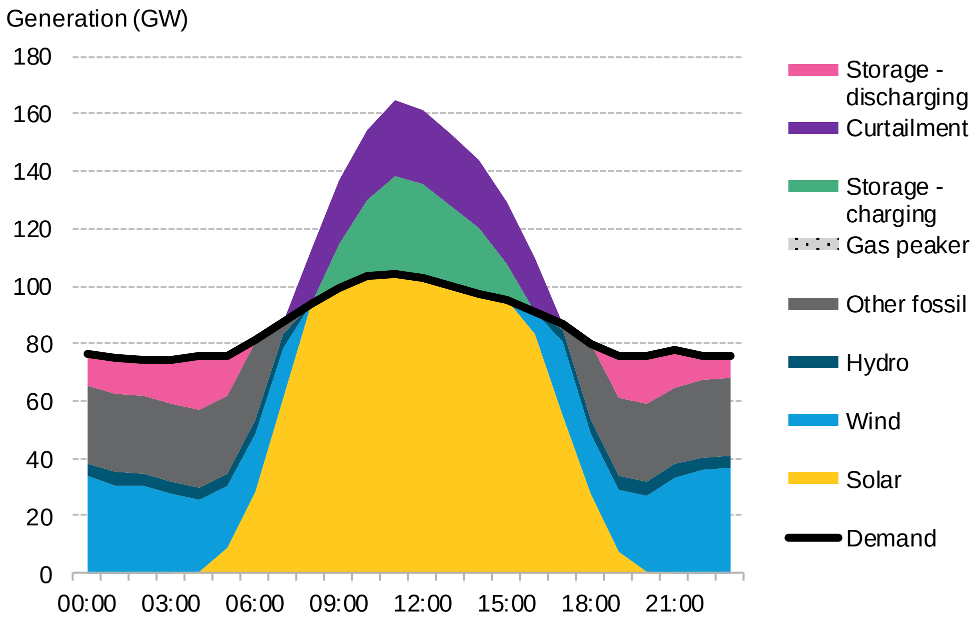
Figure 26: 2040 generation capacity change for high EV uptake scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

In order to better utilise the substantial added volumes of renewable generation, flexibility is provided through additional batteries. These shift excess wind and solar generation to help with evening load peaks, while a modest amount of added gas peakers are available to step in during low renewable generation periods (Figure 27).

Figure 27: Hourly generation during a typical autumn day in 2040 for the high EV uptake scenario



Source: BloombergNEF

With additional EV demand helping flatten the daily load profile, the generation mix also adjusts. Wind generation increases in 2030 (Figure 28) and 2040 (Figure 29), in line with its increased capacity. This is also the case for solar generation, which is almost a fifth higher in 2040. Added renewables provide so much additional electricity that fossil and biomass generation falls by up to 5% in both 2030 and 2040. This translates to a greater reduction in the fossil share of generation.

Figure 28: 2030 power generation change for high EV uptake scenario, versus NEO base case

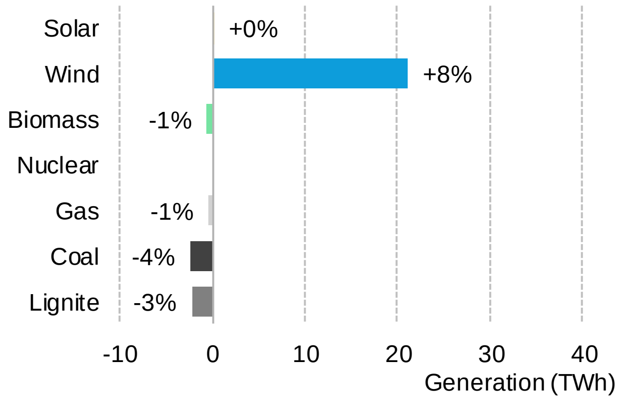
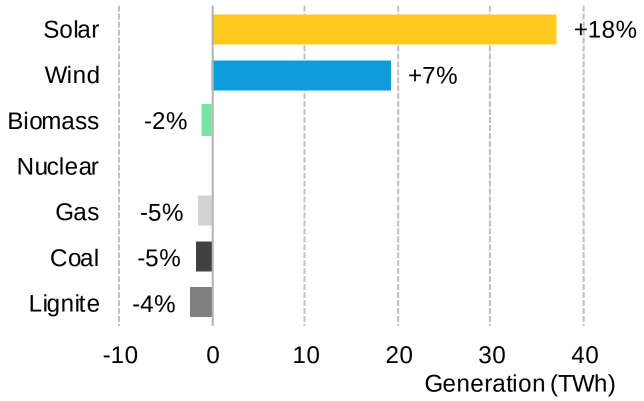


Figure 29: 2040 power generation change for high EV uptake scenario, versus NEO base case

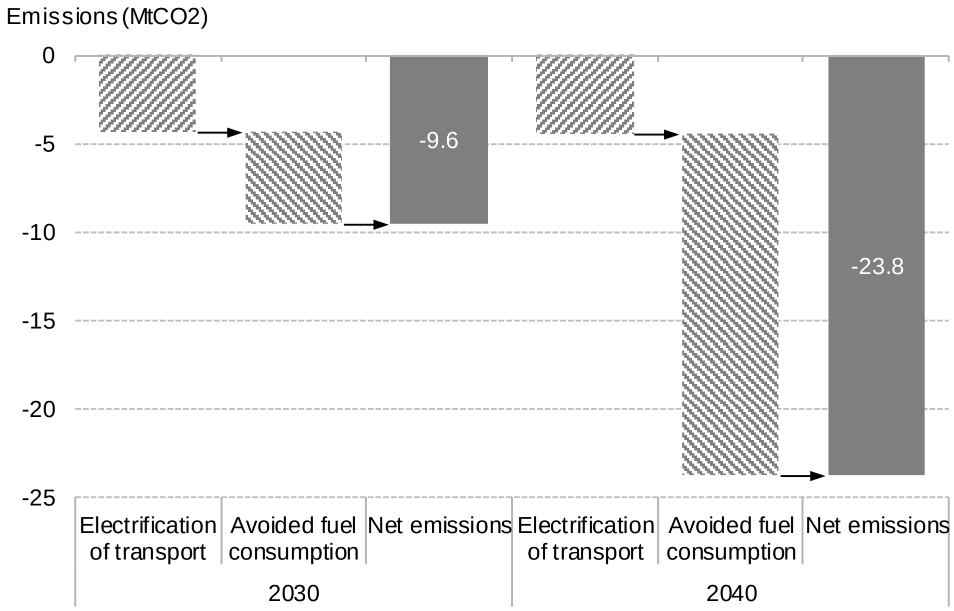


Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

5.2. Implications, benefits and drawbacks of this scenario

EVs are the clearest pathway to decarbonizing road transport. Contrary to popular fears, their addition actually reduces fossil-fired generation, translating into a net cut in power sector emissions even before considering avoided tailpipe emissions. Our analysis shows that the higher EV penetration resulting from a ban on ICE sales in 2040 produces a net reduction in emissions of 9.6 MtCO2 in 2030 and 23.8 MtCO2 in 2040 (Figure 30).

Figure 30: Net emissions after considering avoided fuel consumption, relative to NEO



Source: BloombergNEF

Increasing the number of electric vehicles in Germany helps to better integrate renewables, improving their penetration in the generation mix. And, although the system becomes more expensive in absolute terms due to the extra capacity needed to power more EVs, it has almost no impact on per-MWh power system costs,[4] increasing by less than 1% in both 2030 and 2040 (Table 5).

Table 5: Key metrics for the high uptake of EVs scenario

Metric	Units	2030	2030	2040	2040
		Value	Δ vs NEO	Value	Δ vs NEO
System cost	EURm/TWh	41.0	+1%	48.9	+1%
Emissions	MtCO2	134.2	-7%	90.1	-18%
Fossil capacity as share of peak demand	%	80%	-1%	52%	-7%
Renewable share of generation	%	76%	+2%	84%	+2%

Source: BloombergNEF

Oil displacement and net emissions

To estimate net emissions, we calculate the impact of passenger EVs on oil consumption. In our ICE ban scenarios, we estimate that EVs displace 650 thousand barrels per day (kb/d) of fuel in 2030 and 336 kb/d by 2040 in Germany.

Fuel displacement from EV sales is estimated using the following assumptions[5]:

- Each new EV displaces the sale of a new internal combustion engine (ICE) vehicle of equivalent type – small, medium, large or sports utility.
- The resulting level of fuel demand displaced by each EV is a function of the average fuel economy (measured in miles per gallon, or MPG) and utilization (measured in annual miles travelled) of the displaced ICE. Average vehicle utilization in Europe is around 8,000 miles per year, lower than for the U.S. and China.
- We break down fuel displacement across gasoline and diesel by taking into account the split of gasoline versus diesel ICE sales for each vehicle type in each region.
- We assume that a battery electric vehicle (BEV) displaces 80% of the average miles travelled per vehicle in each region. For plug-in hybrid vehicles (PHEVs), we do not discount vehicle utilization, but assume that a PHEV consumes 50% of the fuel of an equivalent ICE.

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[4] This estimate does not consider additional infrastructure costs nor cost savings from avoided fuel consumption.

[5] Bloomberg subscribers can read more on how we estimate oil displacement in *How Much Oil Are Electric Vehicles Displacing?* (web | terminal)

Section 6. Scenario: high uptake electric vehicles and flexible charging

In an effort to combat air pollution and climate change, countries around the world are incentivizing the uptake of electric vehicles, with some going as far as setting dates from which sales of new internal combustion engine vehicles will be banned. The degree to which the charging of these electric vehicles is flexible to market conditions significantly alters the impact they have on the power system.

In this scenario, we consider the same uptake of electric vehicles as in the previous scenario, but look at the impact on the system of a greater adoption of flexible charging.

How high levels of smart charging might be achieved

This scenario considers the implications of most cars (essentially four out of five) being able to charge at any point in time. There are two ways in which such a high share of flexible load could be achieved, both of which require major investments and behavioural change, and rest on some major assumptions:

- **Ubiquitous smart charging points:** for up to 80% of EVs to be able to charge at any point in time essentially means that they have to be connected to a charge point whenever they are stationary. That means charge points at work, at home, in cities, at restaurants, at shopping malls, at sports centres, at schools, by the lake, by the beach, etc. It also requires drivers to be comfortable with an algorithm controlling and optimizing the car’s charging in response to power market conditions. The latter requires strong financial incentives and policy measures.
- **Many more batteries at charge points:** it is possible to have the same flexible load outcome by having more batteries at charge points. This means using stationary batteries to charge vehicle batteries, whether at home, at public slow charge points or at fast charge points. This disconnects the process of charging from the process of optimizing when to draw power from the grid. This is one example of how batteries could be plentiful for uses other than those analysed in the high battery uptake scenario outlined here.

In both cases, the local network challenges could be substantial. This is especially the case on sunny, wind-still days, when most EVs are charging simultaneously to capture the abundant cheap solar power, overloading local networks. Managing this, alongside the optimization to benefit from cheap energy, will require the kinds of measures outlined in the box at the start of Section 5.

6.1. How this scenario differs from the NEO base case

Input assumptions

This scenario assumes the same uptake of electric vehicles (and its associated increase in electricity demand) as the previous scenario. The key difference is that the share of EVs charging flexibly grows to 80% in the early 2030s, as opposed to the 50% share achieved in the previous scenario and NEO (Figure 34).

Figure 31: Vehicle fleet

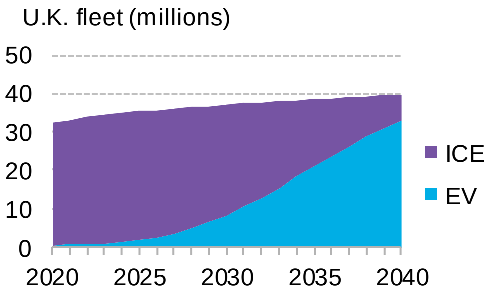


Figure 32: EV demand

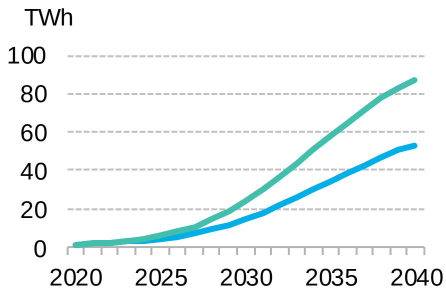


Figure 33: Fixed charging pattern

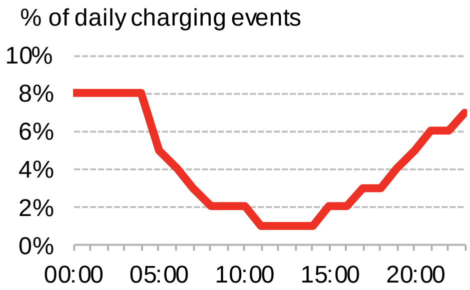
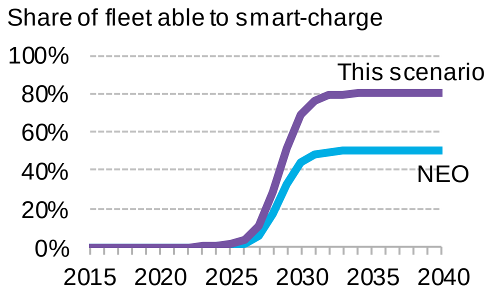


Figure 34: Penetration of flexible charging



Source: BloombergNEF

Outcomes

When up to 80% of electric vehicles – as much as 17% of total electricity demand by 2040 – charge flexibly, effectively load shifting to follow the cheapest sources of generation, it represents a huge source of flexibility. This has a strong influence on the capacity mix in the 2040 timeframe, when the EV load is significant.

By 2040, we see 8% more peaking gas capacity than in NEO, due to the much higher power demand. This figure is slightly higher than the capacity needed under the previous scenario, which has a similar number of EVs but a lower share of flexibility. But there is much less battery capacity. In this scenario, battery capacity grows by 18.6GW instead of 25GW in the previous one. This is because more flexible charging patterns reduce the need for flexibility from batteries. Still, there is substantial storage capacity and it is used to add value to otherwise excess wind and solar during periods of high output when EV charging flexibility alone is not enough.

Another major difference in 2040 is the 65GW of solar capacity addition that is able to be accommodated as a result of flexibly-charging EVs. This is 50% more than the 43GW added in the previous scenario.

The changes in 2030 are less noticeable, as EV penetration by this point is not yet as significant.

Figure 35: 2030 generation capacity change for high flexible EV uptake scenario, versus NEO base case

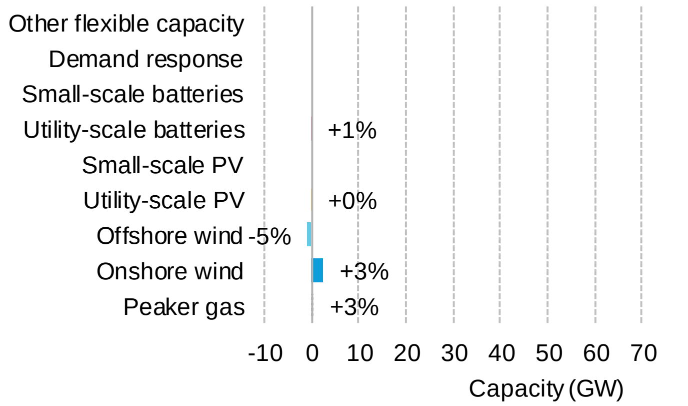
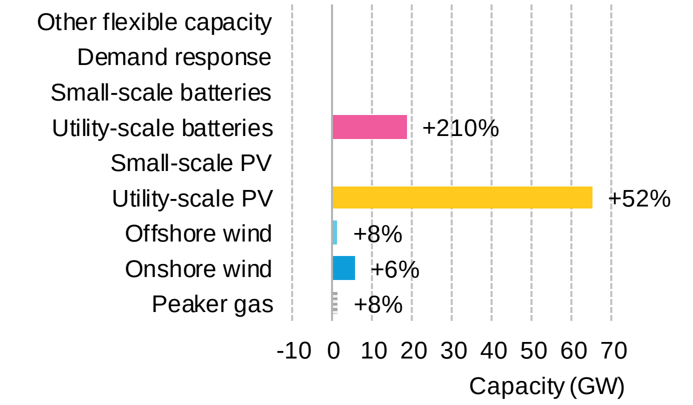


Figure 36: 2040 generation capacity change for high flexible EV uptake scenario, versus NEO base case

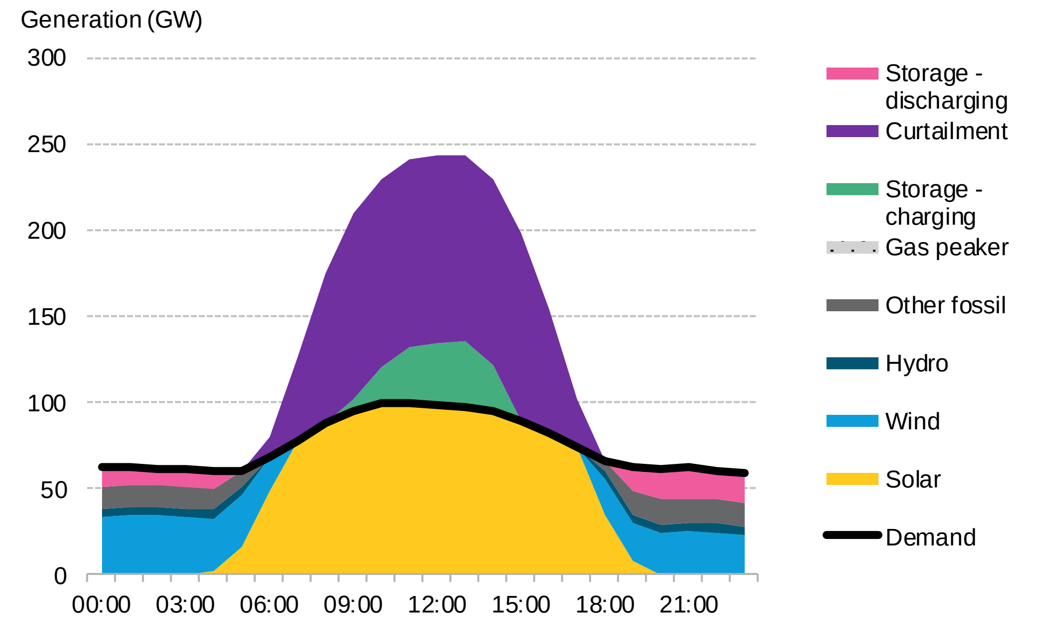


Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Flexible charging has a very strong impact on hourly load profiles, concentrating demand during periods of abundant generation. This suits solar, which would otherwise frequently over-produce. For example, Figure 37 shows the median day of the third quarter of 2040, where the aggregation of EV demand during the middle of a sunny day is clearly visible. During the night, demand falls and batteries shift excess mid-day generation to fill the gap.

Note that even with batteries and flexible demand there is curtailed energy. This reflects the fact that due to the very low cost of solar PV it is more economical to waste some of its generation than rely on more expensive dispatchable generation.

Figure 37: Hourly generation during a typical autumn day in 2040 for the high flexible EV uptake scenario

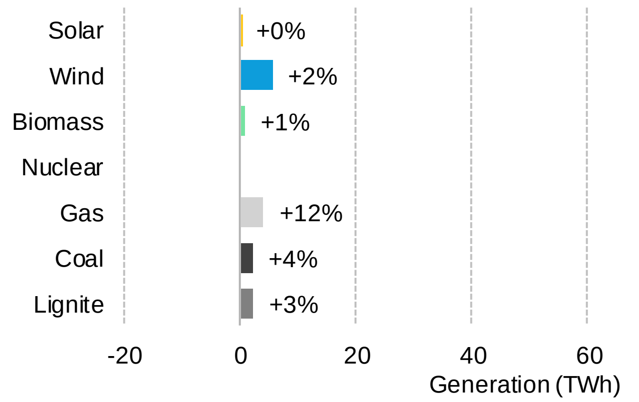


Source: BloombergNEF

The added flexibility provided by flexibly charging EVs in Germany impacts generation in different ways. In 2030, it helps to better integrate renewables and it also increases the utilization of existing fossil assets. This results in more wind and biomass generation, but also more gas, coal and lignite generation, which contributes to meeting EV demand without the need for additional capacity (Figure 38).

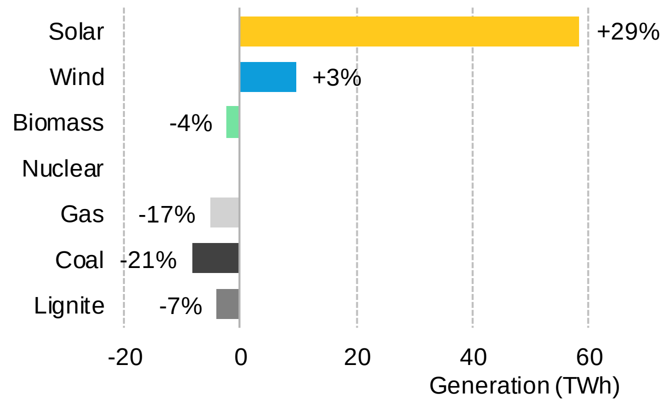
By 2040, the same flexibility from EV charging makes possible the addition and integration of so much more solar generation that there is less need for fossil generation. In 2040, solar generation is 29% higher than in NEO, while gas coal and lignite are 17%, 21% and 7% lower, respectively (Figure 39). This reduction in fossil generation is two to four times greater than in the previous scenario. In other words, the system is burning less fossil fuel for each unit of energy, while at the same time supplying more electricity overall.

Figure 38: 2030 power generation change for high flexible EV uptake scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 39: 2040 power generation change for high flexible EV uptake scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

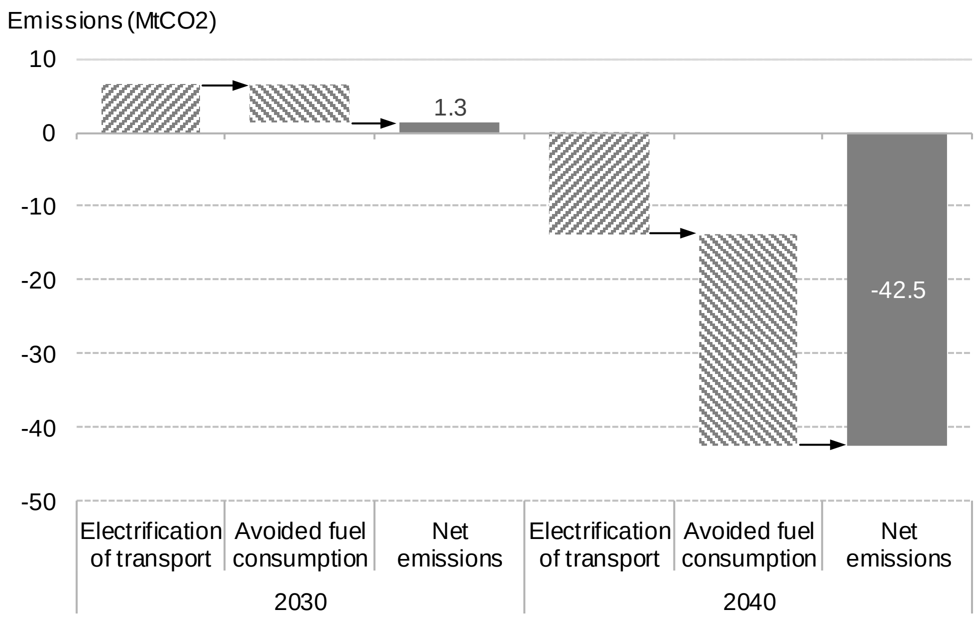
6.2. Implications, benefits and drawbacks of this scenario

EVs are the clearest path to decarbonise road transport and, in the long term, flexible EVs even more so, reducing overall emissions in 2040 even before considering avoided fuel consumption. In 2030, power sector emissions do rise slightly more than avoided tailpipe emissions, but the net difference is relatively small.

In this scenario, emissions in 2030 are about 11MtCO2 higher than in the previous scenario. This is a remarkable result: once again (as in the low-flex scenario) this demonstrates that adding flexibility to a system with significant coal and lignite resources can actually boost production from those plants. Flexibility does not only support renewable energy.

This suggests that a shift to more flexible charging only after 2030 – once coal and lignite play a smaller role in the German energy system – might be the best way to decarbonise the transport sector. What's more, this can contribute to a slight reduction in levelised power generation system costs (Table 6).

Figure 40: Net emissions after considering avoided fuel consumption, relative to NEO



Source: BloombergNEF

By 2040 however, the added flexibility provides a clear benefit. Emissions are about 19MtCO2 lower than the previous scenario, which has a lower share of flexible charging. Adding flexibility to a system dominated by renewables reduces reliance on the remaining fossil-fired plants.

There are of course costs and challenges at other levels: how to incentivise the behavioural change required for flexible charging; how to enable the network to cope with the high local grid loads; and how to pay for the extensive charging infrastructure required.

Table 6: Key metrics for the high uptake of flexible EVs scenario

Metric	Units	2030	2030	2040	2040
		Value	Δ vs NEO	Value	Δ vs NEO
System cost	EURm/TWh	41.0	+1%	47.9	-1%
Emissions	MtCO2	145.0	+1%	80.8	-26%
Fossil capacity as share of peak demand	%	77%	-5%	43%	-22%
Renewable share of generation	%	74%	-1%	86%	+4%

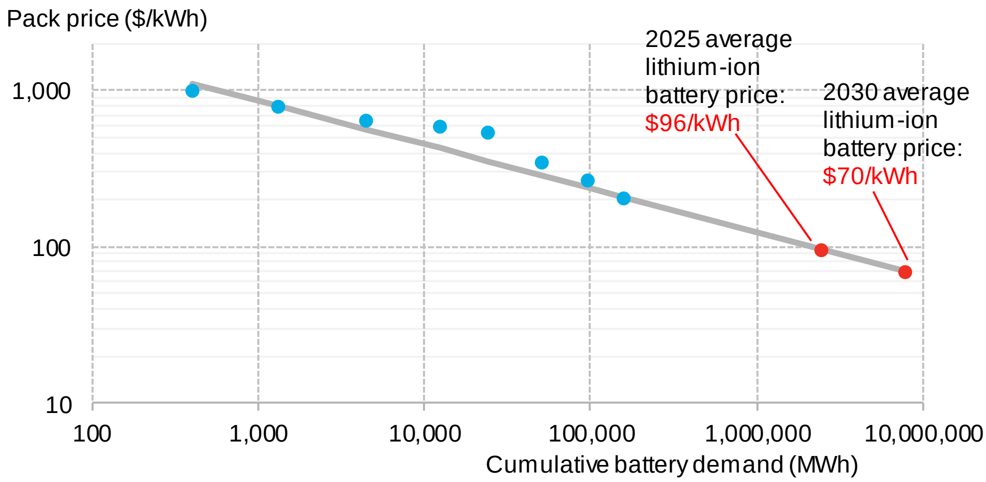
Source: BloombergNEF

Section 7. Scenario: high uptake of storage

Battery storage costs – just like those of wind and solar power – have come down fast. Thanks to technological innovation and scale expansion, lithium-ion pack prices have fallen by 79% since 2010 on the back of increasing annual battery demand from the automotive and portable electronics sectors.

Our data show that lithium-ion battery packs are experiencing an 18% cost reduction for every doubling in capacity. By 2025, we expect that with current lithium-ion battery technology the industry will be able to produce an average battery pack at $96/kWh, and at $70/kWh by 2030 (Figure 41).[6]

Figure 41: Prices and learning rates for lithium-ion battery packs



Source: BloombergNEF

However, battery costs could come down faster than we project, just like wind and solar costs did, and this scenario investigates the impact of this possibility on the German power system. We are already seeing significant investment in manufacturing globally, with production capacity expected to more than triple by 2021. The fight to secure market share in such a growing market could see prices drop faster than our expectations, which are based on recent trends.

The removal of major regulatory barriers, such as the double application of network charges while charging and again when discharging, could also accelerate the growth of battery storage. Equally, direct support or market adjustments to reflect the benefits of battery storage would result in a more favourable environment for batteries. For example, the ongoing overhaul of the U.K.'s frequency response requirements values the fast response times of battery storage.[7]

A breakthrough in technology could also result in a step-change in cost reductions. Our forecasts are based on existing lithium-ion technologies, but breakthroughs in different chemistries, high voltage-cells or solid-state batteries could result in lower costs.

[6] Bloomberg subscribers can read more in our *2017 Lithium-Ion Battery Price Survey* (web | terminal).

[7] Bloomberg subscribers can read more in *New U.K. Frequency Response Products Require Batteries* (web | terminal).

Behind-the-meter versus utility-scale batteries: where will they be?

While the technology is the same, there are important differences in how utility-scale battery storage and smaller-scale storage deployed behind the meter are used, as well as the type of services they can provide to the grid.

Where batteries are deployed will depend on a range of conditions – retail and wholesale power prices, deployment of rooftop PV, market design (eg, capacity payments, balancing requirements).

For example, in Germany, retail power prices are relatively high and many households have rooftop PV systems. As a result, storage is mainly deployed behind the meter and utilities have created interesting business models.

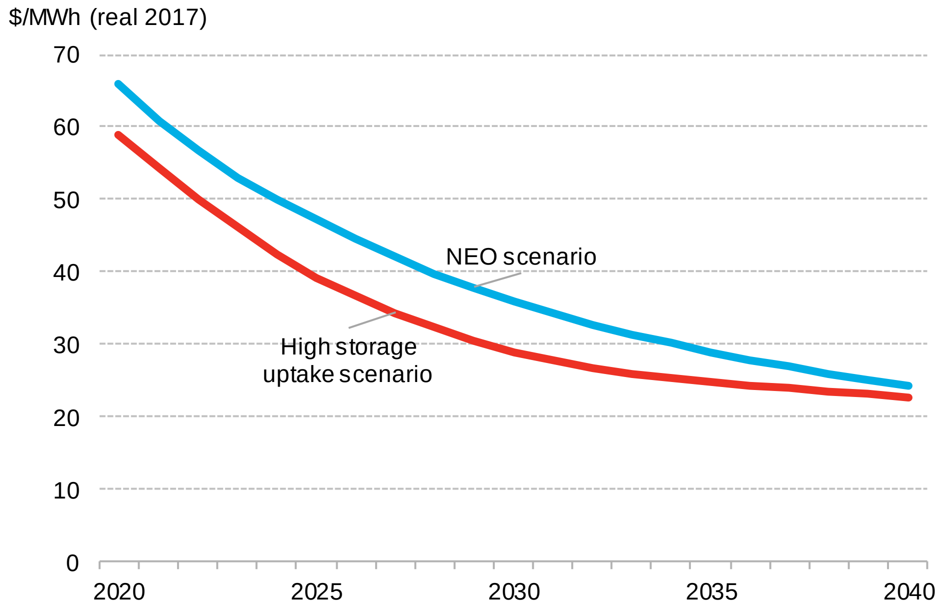
On the other hand, the U.K.'s capacity market and enhanced frequency response scheme have incentivised the deployment of hundreds of megawatts of large-scale battery storage.

7.1. How this scenario differs from the NEO base case

Input assumptions

To reflect a low-cost battery scenario, we used the parameters on the lowest end of our cost range. This gives us a reduction in the levelised costs of finance for battery storage of roughly 10% over the forecast period – the difference is greater in the short-term, at around 17% lower costs, and smaller in the long-term, with a cost reduction over NEO of 6% in 2040.[8]

Figure 42: Battery storage levelised cost of finance[9]



Source: BloombergNEF

[8] It is worth noting that our NEO scenario already takes an aggressive view on storage costs.

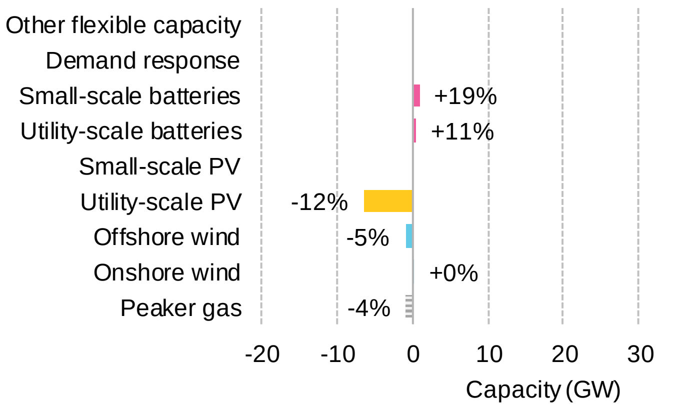
[9] The levelised cost of finance is the long term offtake price on a MWh-basis needed for a project to pay back its capital costs and hit the equity requirements of investors; it excludes variable costs such as fuel, carbon or charging costs in the case of batteries.

Outcomes

Cheaper storage results in more build: relative to our NEO base case, 1.4GW or 13% more batteries are built by 2030. Most of these additions come from small-scale storage, driven by consumer uptake on the back of high retail prices. The main effect of this extra battery capacity is to reduce the need for almost 7GW of the solar capacity in NEO by that year. In addition, the system also requires about 1GW less of both peaking gas capacity and wind (Figure 43).

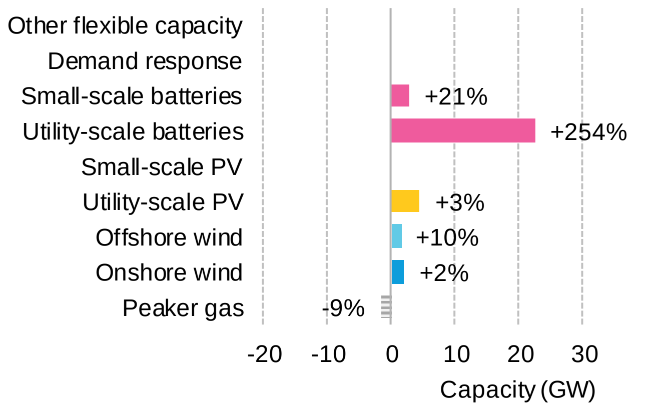
By 2040, there are 25.3 more gigawatts of battery storage than in NEO, an increase of 53% mostly coming from utility-scale batteries, which more than tripled (Figure 44). This additional battery capacity is able to make better use of excess renewable energy by shifting it to times of high demand when fossil capacity would have been required, meaning 1.6GW of peaking gas capacity can be replaced.

Figure 43: 2030 generation capacity change for high storage uptake scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 44: 2040 generation capacity change for high storage uptake scenario, versus NEO base case



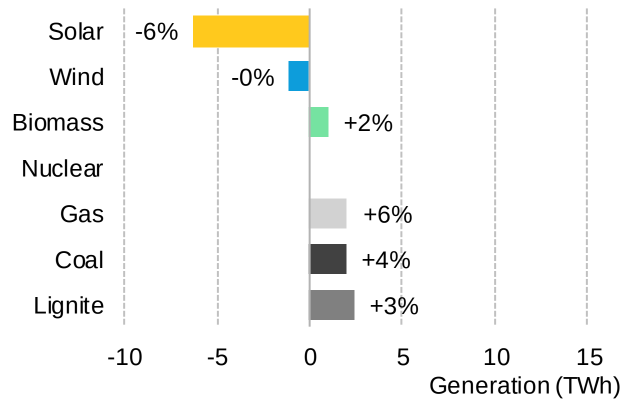
Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

The amount of added battery capacity, however, is much greater than the amount of backup fossil capacity it is able to replace, at a ratio of roughly 16 to 1 in MW terms. This illustrates how, by 2040, the real value of fossil backup capacity is coming online to meet peak demand in periods when there is little renewables output over several consecutive days, where batteries would struggle to recharge.

More storage capacity may reduce wind and solar capacity by 5% and 12%, respectively, in 2030, but it also reduces curtailment of renewables, which, in turn, increases their utilization. Thanks to batteries, the reduction in solar and wind generation (Figure 45) is less in proportionate terms than the corresponding reduction in capacity (Figure 43). The net result is that solar capacity factors increase by 7% and those of wind by 5%. However, there is still a need for more generation, which is met by biomass and fossil generators (Figure 47).

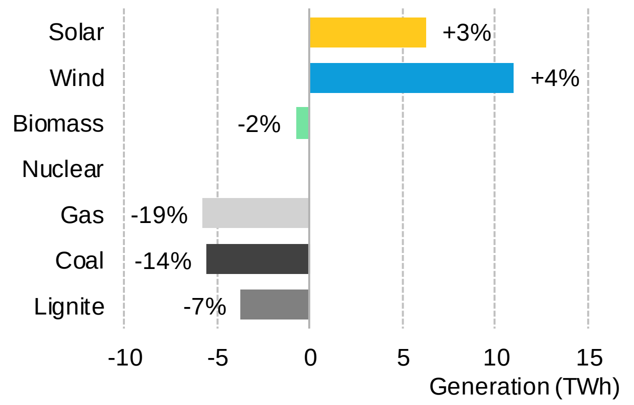
Once again, we see that in 2030 adding more flexibility (in this case, more energy storage) actually supports the burning of gas, coal and lignite. This reiterates the lessons from the previous scenario: that adding flexibility in a system containing significant coal and lignite resources can lead to higher emissions as these plants are aided by the additional flexibility.

Figure 45: 2030 power generation change for high storage uptake scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 46: 2040 power generation change for high storage uptake scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

In 2040, solar and wind generation are 3% and 4% respectively above the equivalent figures in NEO. On the other hand, gas, coal and lignite are down 19%, 14% and 7% (Figure 46). This shows that what storage could not achieve in 2030 it can achieve in 2040: reducing the need for fossil generation by distributing large amounts of renewable generation throughout the day (Figure 48). In this way, storage allows wind and solar generation to grow in proportion to capacity, without incurring a penalty in capacity factors.

Figure 47: Hourly generation during a typical autumn day in 2030 for the high storage uptake scenario

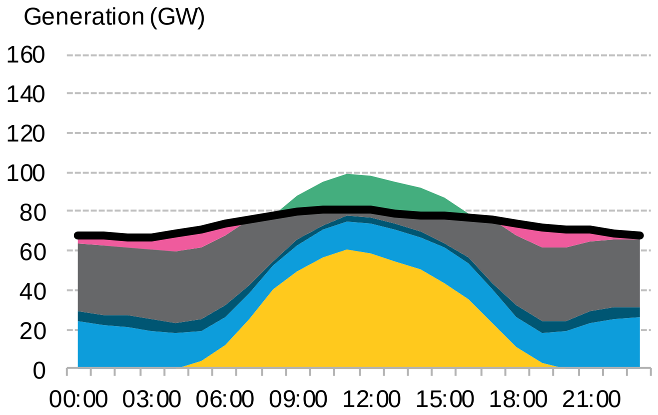
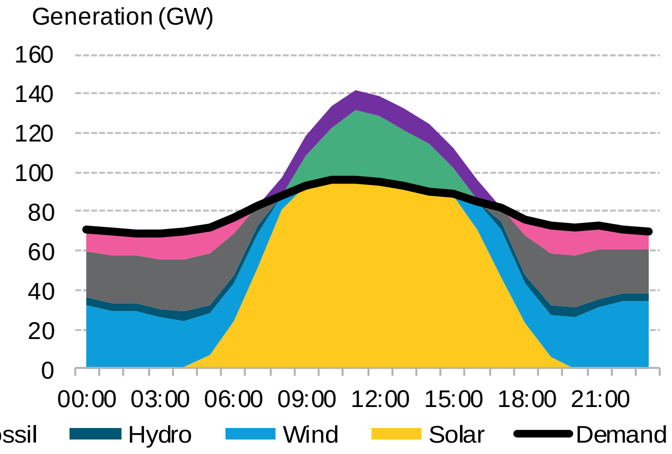


Figure 48: Hourly generation during a typical autumn day in 2040 for the high storage uptake scenario



Source: BloombergNEF

Source: BloombergNEF

7.2. Implications, benefits and drawbacks of this scenario

Cheap batteries can help the energy transition by adding value to renewables. They also increase the utilization of existing capacity and defer investment in further generating capacity. Such deferral means that, because of continuing renewable energy cost declines, capacity built later on will be cheaper. This means that adding cheap storage does not add much in the way of system costs.

The addition of cheap storage in Germany boosts the utilization of existing capacity by 2030 – including fossil assets – which results in an increase in emissions of 5 $MtCO_2$ in that year. However, by 2040 it contributes to decarbonisation, with total emissions 11% lower than in the NEO scenario, equivalent to a reduction of 11.7$MtCO_2$ in that year. Batteries are a good way to shift energy across hours or days, where they can contribute significantly to meeting peak demand. However, there is little batteries can do to help meet demand during extended periods of low renewables output. Thus, a system running on batteries is not capable of completely displacing fossil peaking capacity. This would require zero-carbon seasonal storage or dispatchable generation.

Table 7 summarises the key metrics for the scenario and compares them to the NEO base case scenario.

Table 7: Key metrics for the high uptake of storage scenario

Metric	Units	2030	2030	2040	2040
		Value	Δ vs NEO	Value	Δ vs NEO
System cost	EURm/TWh	40.9	+0%	48.6	-0%
Emissions	$MtCO_2$	148.9	+4%	97.8	-11%
Fossil capacity as share of peak demand	%	79%	-2%	54%	-3%
Renewable share of generation	%	74%	-1%	85%	+3%

Source: BloombergNEF

Section 8. Scenario: high uptake of flexible demand

In order to reduce costs, encourage and integrate the uptake of clean energy and increase customer participation, regulators are making changes to incentivise services like demand response.

These efforts include introducing financial mechanisms that reward utilities and distribution companies for contracting distributed energy resources in place of capital investments – a departure from traditional regulation in which the addition of new capital assets is the main source of profits.[10] Under the new approach, network operators are allowed to earn a return on operational expenditure for distributed energy resources. Treating any mix of capex and opex equivalently removes the preference to own and operate assets over seeking third-party alternatives.

Demand-side resources are also being offered broader access to participate in wholesale energy, capacity and ancillary service markets. And as smart meters are more widely adopted, dynamic tariffs will help to encourage demand shifting among business and household consumers.

If successful, these new approaches could have widespread ramifications and result in a more widespread uptake of demand response and other services. This scenario considers the impact of greater demand response uptake on Germany's power generation system.

How commercial and industrial loads could be managed more actively

- Data centres are a good example of a large commercial load that has the potential to support the power grid and be compensated for the flexibility services provided. Data centre operators require resilient power infrastructure no matter what happens in the grid. To achieve this, they typically deploy UPS systems and on site generation with back-up generators. Eaton's UPS-as-a-Reserve (UPSaaR) enables data centre operators to make money from their existing UPS systems by helping energy providers balance sustainable energy demands. Large data centre operators, such as co-location and cloud service providers, can be compensated for immediate adjustments to power demand that help the grid avoid power outages, without compromising critical loads.
- Eaton has performed two pilots with TSOs. One, with Svenska Kräftnet, and another with Statnett, in Norway. Both pilots proved that UPS technology fits perfectly for rapid frequency regulation type services. Frequency regulation in this context is more focused on very short time frequency variations – timescales of seconds – caused by minute variations in production, disturbances and also by reduced amounts of inertia in the grid.
- While UPS systems today are not used to reduce peak demand or time of use, this is certainly possible with investment in larger batteries. UPS technology could easily be linked to various energy management schemes behind the meter, or more demanding grid support schemes. With new business models, such as revenue sharing and aggregators investing in additional hardware required for more lucrative services, this is possible today

[10] Bloomberg subscribers can read more in *Grid investment gives way to distributed energy* (web | terminal)

8.1. How this scenario differs from the NEO base case

Input assumptions

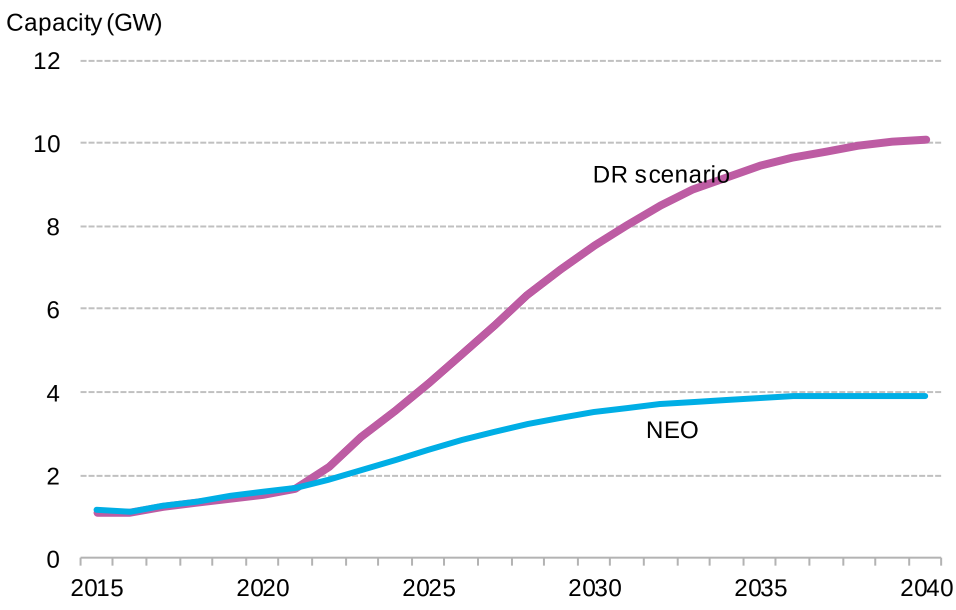
The main difference between this scenario and NEO are the higher levels of both dispatchable and non-dispatchable demand response:

- Dispatchable demand response is load that can be reduced voluntarily for a short period and for a limited number of times a year (we assume four hours and 20 times per year). This is actually a form of minor demand destruction and its main benefit is to reduce peak-time generating capacity requirements.
- Non-dispatchable demand response, on the other hand, is dynamic load that shifts in response to market signals such as time-of-use pricing. Much like EV charging, it is able to accommodate larger amounts of renewable energy generation.

In Germany, we assume that dispatchable demand response could reduce peak load by up to 7.2% in 2030 and 9.3% by 2040, compared to 3.8% and 4.9% in our base-case NEO scenario. A figure of 9% represents a very substantial fraction of the economy able to curtail demand to avoid peak loads (and related charges) – even if only a few times a year and for a short period. However, similar levels of demand response have previously been procured in the U.S.'s PJM market.

Non-dispatchable demand response capacity is 1.6GW in 2030 and 2.2GW in 2040, versus 0.6GW and 1.1GW in NEO, respectively. This is equivalent to assuming that roughly 2% of system peak load could be moved to different times of day

Figure 49: Demand response capacity

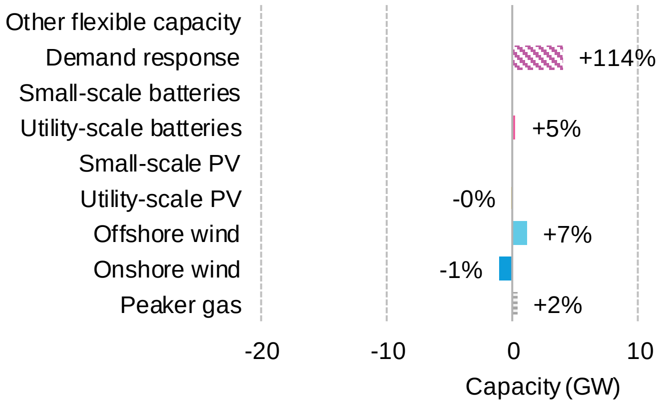


Source: BloombergNEF

Outcomes

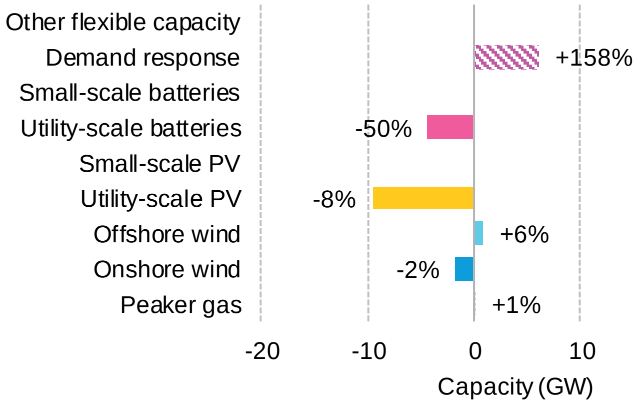
In a future with higher deployment of demand response, Germany might not see significant changes over the next decade, but eventually it would need less battery storage and solar capacity. Offshore wind's more regular generation profile is a better match for demand response and the system tilts toward more offshore rather than onshore capacity, in spite of the former's higher costs.

Figure 50: 2030 generation capacity change for high demand response scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 51: 2040 generation capacity change for high demand response scenario, versus NEO base case

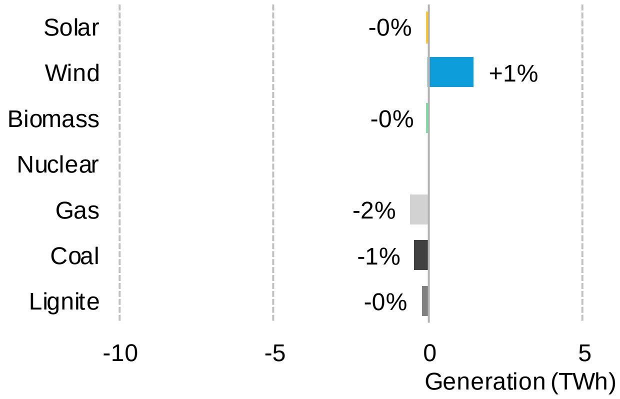


Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

In 2030, the system looks relatively unchanged, adding only some 300MW of fossil peaking capacity and 200MW of batteries compared to that in NEO. Overall wind capacity remains unchanged, swapping one gigawatt of onshore for a gigawatt of offshore capacity (**Error! Reference source not found.**).

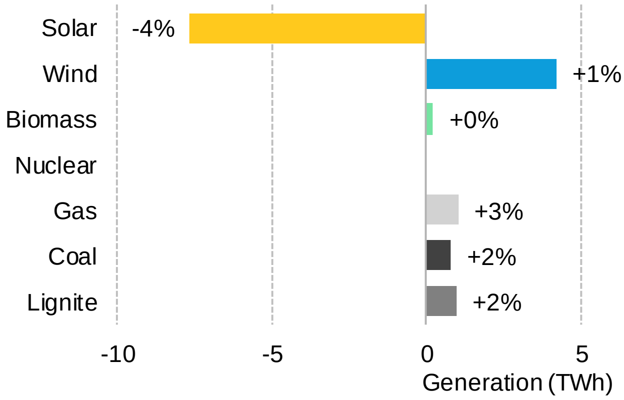
By 2040, the impacts start to be felt. The increase in demand response results in an 8% reduction in solar capacity against NEO, equal to 9.6GW. There is a slight reduction in onshore wind of 1.7GW in favour of 0.9GW of offshore wind (**Error! Reference source not found.**).

Figure 52: 2030 power generation change for high demand response scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 53: 2040 power generation change for high demand response scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Demand response can reduce the need for battery capacity by 4.4GW, or half the utility-scale capacity in NEO in 2040. This is primarily because dispatchable demand response is able to shave many of the peaks for which batteries would have been required – illustrating that demand response and storage will compete for some of the same opportunities in future. On the other hand, dispatchable demand response, which can only be called upon for up to four consecutive hours, is not able to displace backup fossil generators, which are needed for days at a time during long periods of low renewable generation.

The preference for offshore wind, and its corresponding higher capacity factors, is noticeable in the generation mix, with wind generation higher by 1% in both 2030 (Figure 52) and 2040 (Figure 53), despite overall wind capacity staying constant or falling. For solar, there is no change in 2030. In 2040, although there is a 4% reduction in solar generation over NEO levels as capacity falls, solar's utilization increases – showing that non-dispatchable demand response in particular boosts the usefulness of solar generation by shifting load to hours with high solar output.

Dispatchable generation is a different story. There is a slight reduction in fossil and biomass generation in 2030, but interestingly, by 2040, they go up by up to 3%, compared to the levels in NEO. This increase is not particularly notable, since capacity remains unchanged, but it is the result of demand response contributing to the utilization of existing assets.

8.2. Implications, benefits and drawbacks of this scenario

Demand response can reduce the need for other flexible technologies like battery storage. It also increases capacity utilization, making more efficient use of the generation fleet. This means the same level of electricity demand can be met with less capacity. In terms of costs, the benefits of demand response are of the same magnitude as the expense of implementing it, resulting in practically the same system costs as in the NEO scenario (Table 8).

The extent to which demand response can displace fossil capacity is primarily a function of the frequency and duration of dispatchable demand response activation. These two parameters have a drastic impact on how much capacity demand response can displace. In other words, such capacity is less effective at displacing fossil plants if it is needed for many events during the year, or if those events last a long time. In the case of Germany, demand response has only a marginal impact on the need for backup fossil capacity. This is at least in part due to the presence of energy storage, which is displaced first by demand response. It is likely that, if storage were not present in the first place, then demand response would be playing the role of displacing fossil capacity in 2040 (as storage does in the previous scenario).

By boosting the utilization of existing assets, adding demand response results in less renewables curtailment. This is most evident in 2030, where more wind generation is used, displacing fossil generation and resulting in a net emissions reduction of about 1MtCO2 versus NEO.

But boosting utilization can also result in higher fossil generation and emissions. By making better use of fewer assets, less new (renewables) build is required. As a result, the remaining fossil plants find their economics strengthened and generate more. This is the case in 2040, where a reduction in solar generation gives way to a rise in coal and gas generation. This, in turn, boosts emissions by 2% against NEO levels, or roughly 2MtCO2 (Table 8).

The following table summarises the key metrics for the scenario and compares them to the NEO base-case scenario.

Table 8: Key metrics for the high uptake of flexible demand scenario

Metric	Units	2030	2030	2040	2040
		Value	Δ vs NEO	Value	Δ vs NEO
System cost	EURm/TWh	41.0	+1%	48.6	-0%
Emissions	MtCO2	142.8	-1%	111.7	+2%
Fossil capacity as share of peak demand	%	81%	+0%	55%	-1%
Renewable share of generation	%	75%	+0%	82%	-0%

Source: BloombergNEF

Section 9. Scenario: interconnection to the Nordics

The interconnection of neighbouring systems enables resources to be shared over larger geographical regions. This increases the diversity of generation resources and smooth the aggregated output of variable renewables, thanks to their dispersal over a wider area. In principle, more interconnection results in a less volatile and more flexible system overall.

This is especially true when interconnecting to a region like the Nordics that has unrivalled clean, cheap and flexible resources thanks to the abundance of hydropower. This combination is not only low-carbon and cheap, but also well suited to deal with demand volatility and its corresponding ramping requirements.

Electricity interconnection is a well-rounded source of flexibility that provides access to overseas generation when needed and allows exports of generation that might otherwise be curtailed. This can be viewed as equivalent to seasonal storage from various points of view. It also provides balancing tools to system operators and additional resources in the event of an emergency.

For countries that are in the middle of a transition to a system driven mainly by variable renewables, such as Germany or the U.K., interconnection to the Nordics presents a unique opportunity to increase flexibility. So much so, in fact, that there is a healthy pipeline of interconnector projects currently being developed. This scenario considers the impact of such interconnection on the German power system.

9.1. How this scenario differs from the NEO base case

Input assumptions

We modelled interconnector capacity between the Nordics and Germany based on the existing 2.8GW of capacity and three projects with a combined additional capacity of 2.8GW: a link to Norway, NordLink; and two to Sweden, Hansa Power Bridge I & II (Figure 55). These projects are either being built or have a good chance of going forward, and as such give a good idea of future conditions between the German and Nord Pool markets.

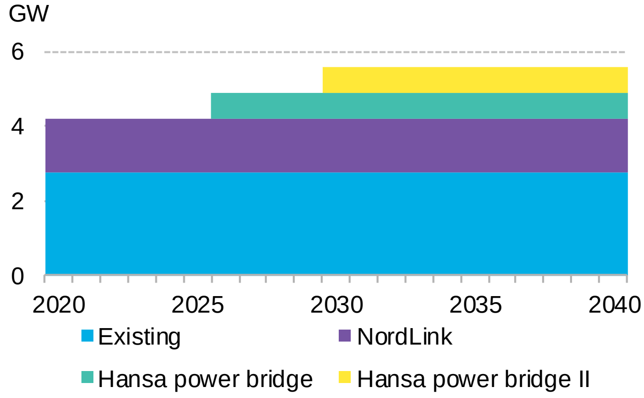
We assume that the NordLink project begins operations in the early 2020s, and that the links to Sweden are commissioned in 2026 and 2030, based on their expected completion dates (Figure 54). This means that the interconnector capacity remains constant from 2030 onwards and any changes in flows between the regions are solely due to market conditions.

Our approach to modelling interconnection

- Our New Energy Outlook methodology, which forms the basis of this report, is a global exercise that does not normally consider interconnection between modelled regions. To incorporate the impact of Nordic interconnection in our model, we added an interconnector class with similar operational characteristics to pumped hydro storage. We assigned it a short-run marginal cost slightly below that of Germany's fossil generators and energy reserves that reflect the Nordics' export potential. We also assumed that 50% of line capacity can be relied upon at all times – i.e. the interconnectors contribute at least 50% of their nameplate capacity to the German system to help meet peak load.

- This ensures that the interconnector acts as an alternative to fossil generation without exceeding available energy or capacity in the Nordic system. We assumed that Germany only exports excess energy that would have otherwise been curtailed.

Figure 54: Timeline of Nordic interconnection capacity



Source: ENTSOe, BloombergNEF

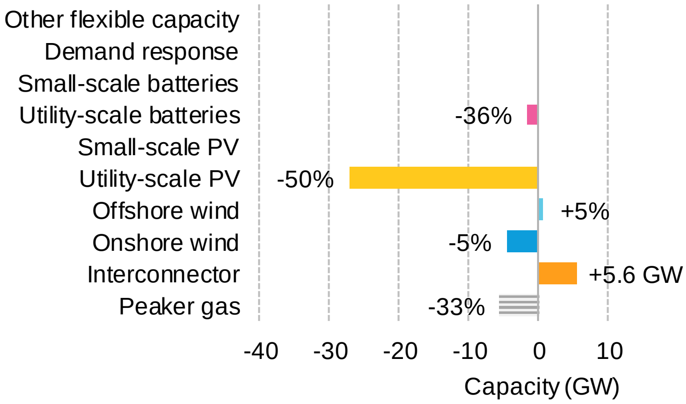
Figure 55: Interconnector projects map

Source: ENTSOe, BloombergNEF

Outcomes

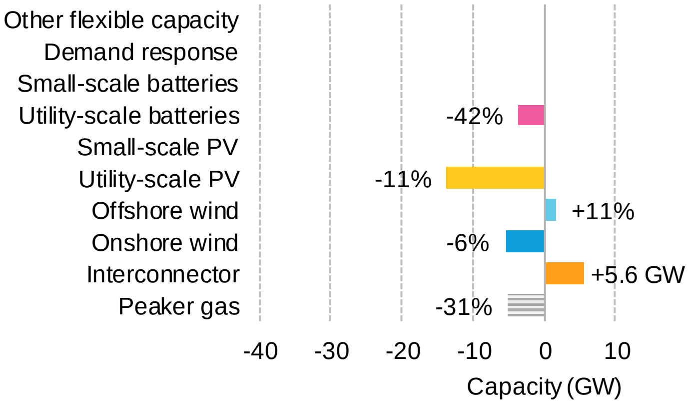
Interconnection between Germany's power market and Nord Pool has a clear impact on the need for peaking gas capacity. In 2030 it cuts gas peaker requirements by 5.5GW compared to NEO, a reduction of 33% (Figure 56). By 2040, the system needs 5.2GW less peaking gas capacity than in NEO, or a reduction of 31% (Figure 57). Equally, battery capacity is reduced by 1.6GW and 3.7GW in 2030 and 2040, respectively. These figures show that interconnection in Germany is an effective substitute for flexible capacity, fossil and otherwise.

Figure 56: 2030 generation capacity change for interconnection scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 57: 2040 generation capacity change for interconnection scenario, versus NEO base case



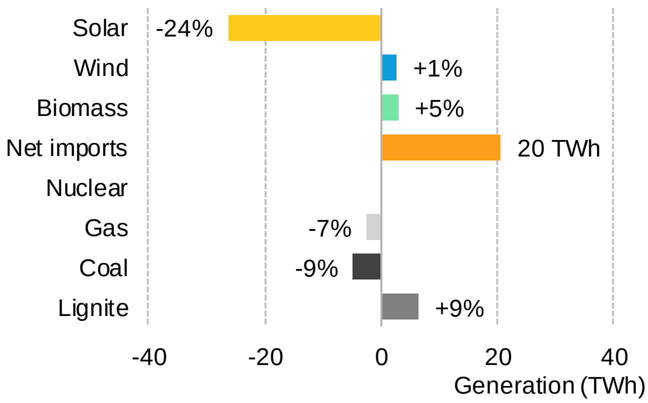
Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Another noticeable dynamic is that the interconnector also displaces solar and wind capacity, which have lower capacity factors due to curtailment and are therefore less cost-effective than imports from the Nordics. By 2030, solar capacity halves compared to NEO, equivalent to 27GW less. By 2040, the interconnector's impact diminishes slightly, resulting in a reduction of 13.7GW, or 11% less than NEO. Wind sees a similar fate, with a reduction of 3.6GW in total in 2030 and 3.7GW in 2040, despite the addition of 1.7GW of offshore wind.

From a generation point of view, having the ability to tap into a different market means imports replace nearly a quarter of solar generation in 2030,[11] while wind is better integrated and increases by 1%. By 2040, solar generation is only 4% lower than in NEO and wind generation increases by 5% – a reflection of the interconnector's ability to accommodate variable renewables through exports (Figure 58).

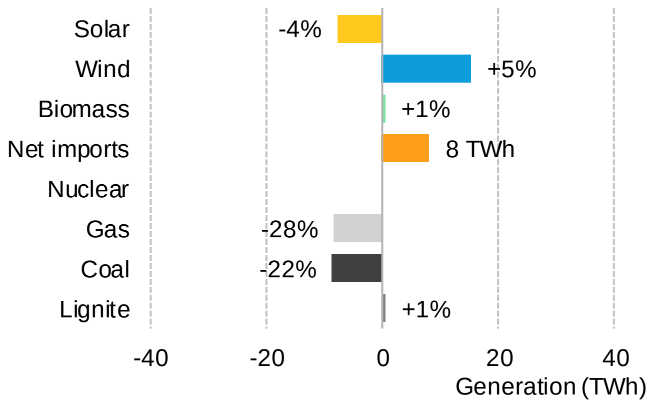
Substituting renewable generation with imports creates a bit more room for biomass and lignite generation, which grow by 5% and 9% in 2030 compared to NEO, but it pushes out coal and gas in a similar proportion, resulting in less fossil generation. By 2040, there is room for 1% more lignite than in NEO, but falls in coal and gas generation of 22% and 28%, respectively, more than make up for that (Figure 59).

Figure 58: 2030 power generation change for interconnection scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

Figure 59: 2040 power generation change for interconnection scenario, versus NEO base case



Source: BloombergNEF. Note: percentages show relative change against the NEO scenario

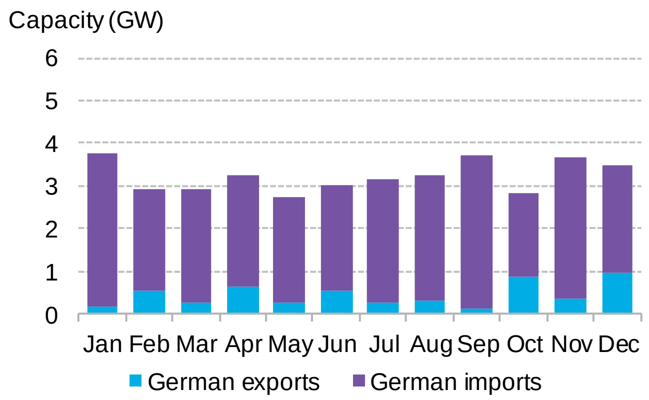
Another important aspect is how the interconnection capacity is utilised: which way does the power flow and how often is it used? As we progress through the forecast period and more wind and solar capacity is installed in Germany, the role of the interconnector changes.

- Around 2023, after nuclear comes offline, the interconnector is mainly used to import cheap power from the Nordics to help meet German demand – though Germany also exports power during some windy and sunny periods. However, as Germany installs more and more variable renewable capacity, this trend slowly starts to reverse.

[11] Note that we include imported power as 'renewable' since it is coming from hydro-dominated Nordic systems – so the displacement of wind and solar are not necessarily detrimental from an emission perspective (see below).

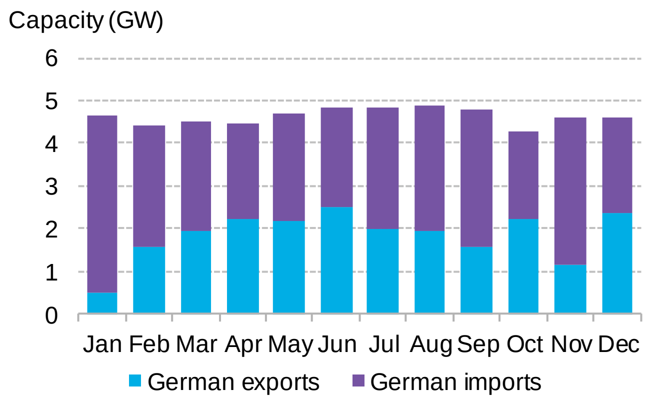
- In 2030 German power imports from the Nordics make up 86% of interconnector flows, with exports only accounting for 14%. The average line utilization throughout the year is 58%, and is used the most during September and November (Figure 60).
- By 2040 we see more balanced flows, with a lower proportion of imports from the Nordics (60% of flows) and a greater participation of exports (40%). Average line utilization for the year increases to 83%. Summer months see the highest utilization, due to excess solar generation and the need for generation as the sun goes down (Figure 61).

Figure 60: Interconnector utilization in 2030



Source: BloombergNEF

Figure 61: Interconnector utilization in 2040



Source: BloombergNEF

This shift reflects the nature of a system increasingly driven by wind and solar, which often generate more than it needs. More importantly, it reflects how the value of the interconnection to the Nordics will shift from providing bulk electricity to become more like a long-duration battery, absorbing excess power from Germany to return it later on – during highly priced hours of low renewables output when flexibility is most needed and valued.

9.2. Implications, benefits and drawbacks of this scenario

Interconnection to the Nordics, and their flexible hydro resources, benefits the system in almost every way. From a reliability perspective, the extra interconnection capacity is an excellent flexible resource that can operate over short and long timescales alike, by shifting energy over hours and across seasons. It also provides an additional source of electricity that can contribute to security of supply.

The interconnector's ability to replace other types of capacity and generation with hydropower has negligible impact in terms of emissions by 2030, but translates into a considerable reduction in emissions later on. By 2040, the system sees a reduction in emissions of 11% against NEO, or just over 12 MtCO2 (Table 9).

From a system cost perspective, the interconnection also proves good value for money, resulting in a reduction of 1-2% (excluding the roughly 3 billion euro cost of building the interconnectors). While at first sight this might seem like a modest reduction, it is an impressive impact from less than 6GW of capacity, in a German market that by 2040 surpasses 400GW of installed capacity. The cost cuts are due to three main factors: the avoided costs of building capacity, access to lower-cost electricity and a reduction in total carbon costs.

Unlike individual technologies such as storage and flexible EV charging, interconnection with the Nordics improves both short-run and seasonal flexibility. This reduces the need for other flexible capacity, and that in turn cuts system costs. It also reduces the need for fossil fuel burn, resulting in fewer emissions. As more renewables are deployed, the value of interconnectors shifts from providing bulk, cheap, clean power to providing valuable flexible power during high-value hours.

Table 9: Key metrics for the interconnection scenario

Metric	Units	2030	2030	2040	2040
		Value	Δ vs NEO	Value	Δ vs NEO
System cost	EURm/TWh	40.4	-1%	47.5	-2%
Emissions	MtCO2	144.0	+0%	96.9	-11%
Fossil capacity as share of peak demand	%	77%	-4%	53%	-4%
Renewable share of generation	%	75%	+0%	85%	+3%

Source: BloombergNEF, Note: net imports included in renewable share of generation

Section 10. Final thoughts

This section presents some overall observations and findings from across the scenarios, and the lessons they provide as Germany prepares for a future power system dominated by renewables. We also provide a comparison of the seven scenarios – though we do this with some caution. This report is not intended to 'pick a winner' from the technologies analysed – all of these technologies will play a part – but comparing scenarios does provide insight into their relative contributions and roles.

10.1. Roles and contributions of each technology

The tables below compare the main outcomes for each technology scenario in 2030 and 2040.

Table 100: Summary of scenario outcomes in 2030

Scenario	System cost	Emissions	Fossil capacity as share of peak demand	Renewable share of generation
NEO (base case)	40.8 EURm/TWh	144 MtCO2	81%	75%
Relative change vs NEO				
Low-flex	0%	-3%	-1%	1%
High uptake of EVs	1%	-7%	-1%	2%
High uptake of EVs and flexible charging	1%	1%	-5%	-1%
High uptake of storage	0%	4%	-2%	-1%
High uptake of flexible demand	1%	-1%	0%	0%
Interconnection to the Nordics	-1%	0%	-4%	0%

Table 11: Summary of scenario outcomes in 2040

Scenario	System cost	Emissions	Fossil capacity as share of peak demand	Renewable share of generation
NEO (base case)	48.6 EURm/TWh	109 MtCO2	56%	83%
Relative change vs NEO				
Low-flex	8%	-15%	19%	3%
High uptake of EVs	1%	-18%	-7%	2%
High uptake of EVs and flexible charging	-1%	-26%	-22%	4%
High uptake of storage	0%	-11%	-3%	3%
High uptake of flexible demand	0%	2%	-1%	0%
Interconnection to the Nordics	-2%	-11%	-4%	3%

Source: BloombergNEF. Note: Colour scales differ between columns, but in all cases green is desirable. Emissions for EV scenarios include a negative contribution from emissions displaced in the oil sector; net imports included in renewable share of generation.

Flexibility supports renewable energy, but it can also support coal

'New' flexible technologies are effective at integrating variable renewable generation, but they can also support fossil generators such as coal or gas. This explains the surprising result that emissions are higher in 2030 in the high-storage and high-flexible EV charging scenarios, and lower in the low-flexibility scenario.

The primary effect of adding flexibility is to make better use of existing assets, and to shift usage towards cheaper forms of generation. By smoothing out some of the volatility, additional flexibility can make it more cost-effective to use a little bit more generation from existing dispatchable fossil plants to fill the now-smaller generation gaps – rather than build more renewable capacity. Fossil generators further benefit as less renewable capacity and smoother net demand profiles mean that their generation is cut into less often.

New sources of flexibility are needed in the near term.

Across all scenarios there is a need for battery storage from the early 2020s onwards. In Germany, by 2025, the storage capacity required by the system in our base case NEO scenario is 5.1GW, and ranges across scenarios from 2.2GW to 6.0GW. Allowing the aggregation of storage to provide grid services as well as rewarding utilities and distribution companies for contracting distributed energy resources are key to supporting these new sources of flexibility that will enable the transition to a high renewable energy system.

Adding flexibility does not solve Germany's coal problem between now and 2030...

We find that through 2030, more flexible EVs, more storage and more interconnection all have the effect of supporting German coal generation, in particular lignite, rather than displacing it. It is important to note that adding flexibility is not the problem here – cheap coal (lignite) is. With its abundance in the system and low price, anything that makes its operating environment more stable enables greater burning of the fuel. To reduce emissions, coal needs to be phased out.

…But it does enable greater renewable penetration and emissions savings by 2040

By 2040, coal's contribution to the system is smaller and renewables are even cheaper. The added flexibility now enables more cheap renewable capacity to be built and integrated effectively, pushing fossil generation out and reducing emissions substantially. This is observed across all of the EV, storage and interconnector scenarios. However, it's worth noting that even then German NEO base case emissions remain relatively high, just 25% down on 2030, highlighting the resilient position of coal and lignite resilient position in the market.

A lack of 'new' flexibility would have a real cost in the long run

The low-flex scenario does not increase emissions by 2030, as it makes up for the lack of flexibility by building lots of extra (renewable) capacity, albeit inefficiently, with very low utilization of the added capacity. This approach reduces emissions as it disrupts lignite and coal generation to 2030. However, by 2040 the implications of such a wasteful approach become clear, with the scenario being 8% more expensive than the NEO base case, and with 19% more fossil-fired backup capacity.

Adding more electric vehicles results in major net emissions savings at little added cost

Even in our high-uptake scenario, where internal combustion engine vehicles are phased out by 2040, EVs do not 'break' the power generation system. System costs are hardly raised while net emissions – after taking into account avoided tailpipe emissions – come down 18% by 2040, or 26% if more of those vehicles charge flexibly. High levels of flexible charging also enable greater renewable penetration and reduce fossil backup capacity by 22% by 2040. However, the impact on the transmission and distribution network may be more significant – see discussion below.

Adding energy storage helps further reduce emissions by 2040

The NEO base case already includes a significant share of energy storage, but in a scenario where storage gets even cheaper, the benefits are significant. By 2040, emissions come down a further 11% (about 12Mt) as result of cheaper batteries. This happens as 3% more renewable power is integrated into the grid and fossil backup capacity is reduced by 3%.

Increasing links with highly flexible markets can improve outcomes across decades

The interconnector scenario delivers 11% power sector emission reductions in 2040, while also making the system cheaper and reducing its reliance on fossil fuel backup capacity. The interconnectors' role changes over the forecast, shifting from providing imports in the early years of the forecast period, especially during shoulder months, to absorbing excess renewable generation, especially in the summer, later on. This means the interconnectors start to behave more like a seasonal storage battery, resulting in a reduction in fossil backup capacity required. This illustrates the versatility of interconnectors when used to connect to a market with a high degree of clean flexibility.

Adding flexible demand reduces battery storage needs but does not affect fossil plants

Adding demand response beyond what is already available in the NEO base-case scenario does not have much impact on the German power system in the ways measured in the tables above. However, it halves battery capacity by 2040, indicating that it is replacing batteries in their role of integrating higher shares of renewable power.

10.2. The problem with coal

'New' flexibility technologies are expected to support renewables and help Germany's grid become cleaner. In our modelling though, adding more of these technologies actually does the opposite and accommodates coal and lignite through 2030, raising power sector emissions compared to the NEO trajectory. It is only much later that the tide eventually turns and emissions are reduced by flexibility.

It is clear from these findings that adding cheap renewables and cheap flexibility alone cannot decarbonise the Germany grid in the coming decade. To do this, Germany needs to work on reducing coal (and especially lignite) generation. The options are:

- Push out coal generation by making it less attractive, for example through higher carbon pricing
- Close coal plants, through a phase-out plan, like the ones being implemented in the U.K. and some other European countries

The challenge for Germany with (EU ETS) carbon pricing is that its lignite is so cheap and its plants so efficient compared to others in Europe that it will take a very high carbon price to phase them out ahead of other plants across the continent. Even the NEO scenario we use as our base case assumes a functioning EU ETS with prices reaching around 30 euros per metric ton in the 2020s. However, with the new EU ETS market stability reserve in place, supply of allowances now responds to the surplus in the market. This means that unilateral actions like coal plant closures can be better absorbed by the market, where before they would have just resulted in lower prices and the same emissions taking place elsewhere in Europe instead. However, the market stability reserve has limitations and there is still a significant risk to the historically fragile EU ETS that such a coal phase-out would undermine carbon prices substantially. The net effect of that would be (potentially more) fossil fuels being burned elsewhere in Europe.

10.3. Getting the market environment right for flexible tech

The scenarios nominally explore technology outcomes, but they can also be seen through a policy lens: policymakers and regulators can help to bring about these outcomes by creating favourable market environments for flexibility sources. Favourable market conditions for flexibility might include:

- Introduction of dynamic power pricing (potentially mandatory) for energy customers – and for electric vehicle charging
- Establishment of frameworks for distribution network operators to share the value of flexibility
- Greater incentives or compensation for rapid-responding resources within capacity and ancillary markets
- Shortening of the trading and settlement interval in the wholesale power market
- Expansion of market access for energy storage and demand-side resources – including aggregated resources – and lower barriers for participation, across capacity, energy and balancing markets
- Equal treatment of interconnectors/overseas resources within these markets

10.4. The glass ceiling of 85% renewable energy

None of the scenarios achieve much more than 80-85% renewable energy by 2040. There are a number of reasons for this: new sources of flexibility such as batteries are unable to fill ‘seasonal gaps’ of weeks and months when renewables production is low; Germany does not have significant hydropower generation; and our model is a least-cost optimization and therefore does not over-build batteries and renewables to boost their share beyond an economic optimum.

There is academic debate on whether or not 100% renewable power is achievable. While this report does not seek to answer that question directly, we do find that going far beyond 85% renewables is likely to require new technologies such as power-to-gas or greater use of bioenergy. Germany also does not have nuclear power beyond the early 2020s, meaning that it cannot rely on this additional source of zero-carbon generation.

10.5. Grids, customers and distributed resources

This study has not investigated the network reinforcement or expansion that would be needed to integrate new renewable energy sources and new forms of flexibility. It also does not analyse in detail the specific characteristics of distributed or customer-sited resources such as small-scale storage. There are several important dynamics, challenges and opportunities that will need to be taken into account:

- It is likely that significant network investments will be required to integrate both bulk and distributed renewable energy sources. Digital grid technologies and innovative commercial arrangements will be part of the solution as penetration rises, and these will play a big role in limiting curtailment and maximising the utilization of both generation and network assets.

- By the same token, distributed sources of flexibility, such as demand response, smart EV charge points, onsite generation and small-scale storage, can help to manage both the system-level flexibility needs analysed in this report and the network congestion challenges above (not examined in this report). These represent an opportunity, particularly for distribution system operators, to take a more proactive role in managing their networks, eg by procuring distributed flexibility through competitive tendering mechanisms.
- Energy storage is perhaps unique as a source of flexibility, in that it can be installed as a customer-sited device, eg at a business or household, or as a utility-scale resource. In this study, both types of storage are included and play a role in providing flexibility at the system level. In the real world, only distributed storage will be able to help manage local network congestion, and only utility-scale storage will have access to wholesale markets – unless aggregation becomes widespread. The relative balance of large- versus small-scale storage in Germany is likely to depend on how regulations and tariff designs evolve.

10.6. EV unknowns

This study has investigated the possible ramifications of an internal combustion engine phase-out, leading to faster EV adoption, and the impact of making EV charging highly flexible. However, there are several important unknowns about the future development of EVs that might lead to quite different outcomes, for example:

- Assuming highly flexible EV charging relies on virtually ubiquitous charging infrastructure, so that EVs can essentially charge whenever called upon by power price signals. Germany is currently far from this situation – and even if charging infrastructure becomes widely available, dynamic EV charging will require the consent of customers.
- If instead a large portion of EV charging takes place at rapid charging sites, this might have a negative impact on the power system – it could cause large ramping events, and reduce the opportunity to time charging to coincide with renewable generation. These issues could potentially be managed by having onsite storage, as is planned by some charging operators. Overall, the impact of rapid charging requires further work.
- Other future changes, such as vehicle-to-grid storage or autonomous fleets, could further alter the outlook for how EVs interact with the power system. These were not examined in this study.

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