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63-74%

Renewable generation in the U.K. and Germany by 2040

21-38 GW/hr

Maximum ramp rates in the U.K. and Germany by 2040

70-97 GW

of back-up capacity are still needed in 2040 in the U.K. and Germany

Beyond the Tipping Point: Summary Version

Flexibility Gaps in Future High-Renewable Energy Systems in the U.K., Germany and Nordics

This document summarizes a study conducted on high-renewable power systems by Bloomberg New Energy Finance, commissioned by Eaton in partnership with the Renewable Energy Association. The study builds on BNEF's New Energy Outlook to highlight how quickly wind and solar could become the dominant sources of power generation, and explores the shape and scale of the flexibility challenge that will arise.

This is a summary of the main findings, to request a copy of the full study or briefing with an analyst, please contact Eaton directly at: veragrishchenko@eaton.com.

Introduction

Bloomberg New Energy Finance, in partnership with Eaton and the Renewable Energy Association, has authored a study highlighting how quickly wind and solar could become the dominant sources of power generation on an economic basis, and what this will mean for system flexibility needs. The study is focused on Germany, the U.K. and the Nordics (Norway, Sweden, Denmark and Finland, analysed as a single bloc).

The study builds on BNEF's New Energy Outlook 2017, using data from that report to show the economic tipping points that will lead to accelerated renewable energy deployment – and how the system would look in 2030 and 2040 as a result.

By using five years of historical demand and renewable production data, and applying this to a future high wind and solar power system, we have investigated what the hourly, daily, weekly, monthly and seasonal flexibility needs will be in 2030 and 2040. We also provide data for 2017 as a comparison, as well as a fourth, extreme scenario where total wind and solar generation is equivalent to annual power demand.

Below we summarize the main findings.

1. Economic tipping points

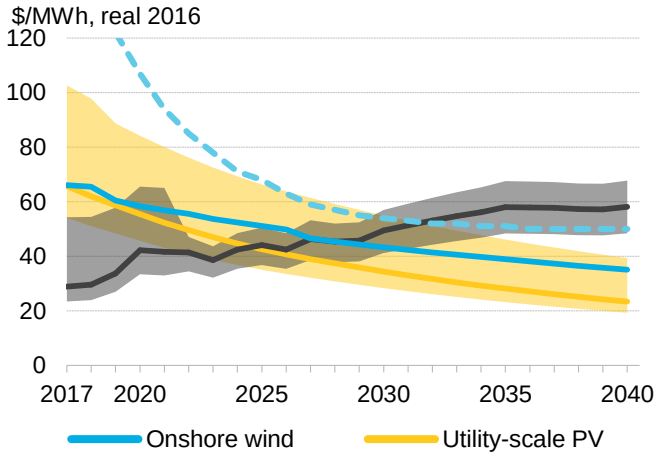
Rapid cost reductions in wind and solar power make them the cheapest sources of electricity in Germany and the U.K., driving the shift to high-renewable power systems.

- As solar and wind costs continue to come down across Europe there is a significant acceleration in the shift to these power sources for electricity generation over the coming 20 years. This transition to a high-renewable energy future happens through mass deployment of renewable energy both at utility-scale and behind the meter (as declining costs make the economic case increasingly compelling for homeowners and businesses).
- Bloomberg New Energy Finance's most recent New Energy Outlook identifies two tipping points, where the competitive tension between different energy technologies plays out:

BNEF

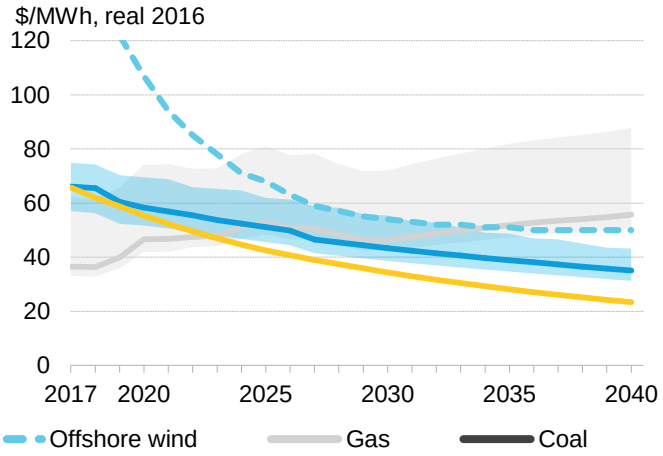
- We have already today reached the first tipping point in most of Europe, with wind and solar having become the cheapest options for new power generation. Energy produced by these two technologies is already less expensive than that from new gas or coal plants.
- By the end of the 2020s, the second tipping point is reached: the cost of the power produced by most new wind and solar projects falls below that of existing gas and coal plants.

Figure 1: LCOE forecast for wind and PV, and generation cost range of existing coal in Europe



Source: Bloomberg New Energy Finance - 2017 New Energy Outlook

Figure 2: LCOE forecast for wind and PV, and generation cost range of existing gas in Europe



Source: Bloomberg New Energy Finance - 2017 New Energy Outlook

- These tipping points mean that by 2040, driven by wind and solar growth, the percentage of electrical energy produced from renewables more than doubles from today's levels in the U.K. and Germany – to 63% and 74% respectively.
- In the Nordics, renewables including hydro already represent nearly three quarters of the power supply. By 2040, 78% of power is generated from renewable sources, 67% by hydro alone.

2. Effects of renewable energy

In 2030 and 2040, variable renewables meets more demand, more of the time – impacting other generators and creating opportunities for flexibility, including storage, flexible demand and interconnectors

- In 2017, variable renewable generation (wind and solar) rarely meets more than 25% of hourly demand in the U.K. and 37% in Germany. In 2040, these resources contribute to more than 55% of hourly demand in the U.K. and 65% in Germany for over half of the year.
- With increasing frequency, wind and solar energy alone could exceed total demand in the U.K. and Germany. This is particularly important in Germany during summer due to the greater deployment of solar capacity.
- In 2030, less than 1% of U.K. and 3% of German wind and solar generation is curtailed or 'wasted'. By 2040, this rises to 3% and 16% respectively (assuming that demand and storage do not flex to accommodate the excess). In the U.K. that means 750 hours when output

exceeds demand (the equivalent of roughly one month) and 2,300 hours in Germany. (These figures do not account for grid and other constraints, which could lead to much higher levels of curtailment).

- However, even in 2040, we see entire weeks and months where wind and solar produce little energy, so other resources must meet 80% and 72% demand respectively in the U.K. and 85% and 63% in Germany.
- As a result, the total back-up capacity needed in 2040 is much the same as in 2017 in both the U.K. and Germany. That means 70GW in the U.K. and 97GW in Germany of dispatchable resources (generation, storage, flexible demand, interconnectors) are needed in 2040 to meet peak demand during periods of low wind and solar generation.
- But this back-up capacity is used less and less often. Average utilisation of non-wind and solar capacity falls from about 50% in 2017 to around 30% in both the U.K. and Germany by 2040. This hurts the economics of certain plants, mainly combined cycle gas turbines, as well as coal plants in Germany.

Figure 3: Peak output of 'other generators' in the U.K.

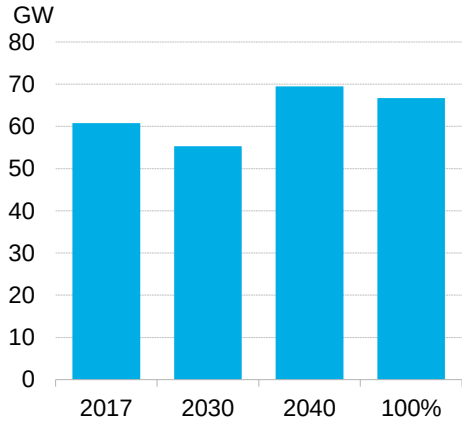


Figure 4: Energy generated by 'other generators' in the U.K.

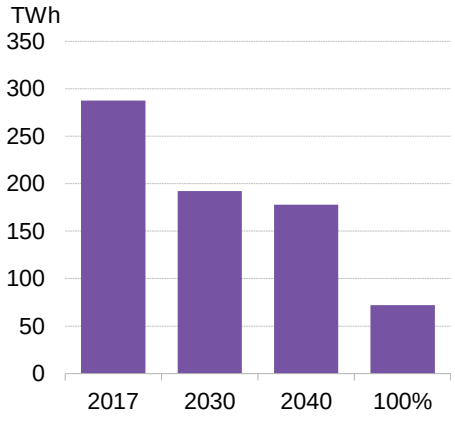
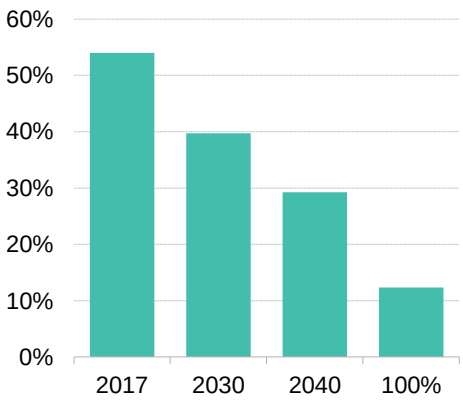


Figure 5: Utilization of 'other generators' in the U.K.



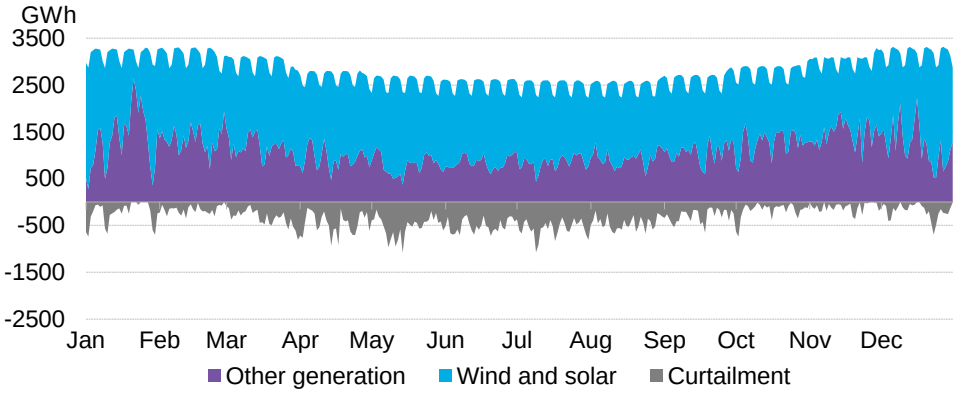
Source: Bloomberg New Energy Finance. Note: 'Other generators' are all resources other than wind and solar.

3. System volatility

System volatility increases markedly in the U.K. and Germany. This creates a very challenging environment for 'baseload' technologies such as nuclear, coal and lignite and increases the need for flexible, fast-acting technologies.

- As wind and solar production rise and fall, other flexible resources need to ramp up or down to balance them from hour to hour. The need is greatest at times when demand is also rising or falling.
- According to BNEF modelling, in 2017 the maximum U.K. ramp rates are 10GW/hour up and 11GW/hour down and 13GW/hour up and 11GW/hour down in Germany. This represents roughly one-third of the U.K. gas fleet turning on or off in an hour.
- By 2040, the highest U.K. ramps are 21GW up and 25GW down – equivalent to around 20-25% of the U.K.'s entire generation fleet turning on or off in one hour. The numbers for Germany are even higher at 38GW up and 34GW down – equivalent to 40% of its dispatchable fleet turning on or off in a single hour.

Figure 6: Daily generation in Germany, 2040



Source: Bloomberg New Energy Finance

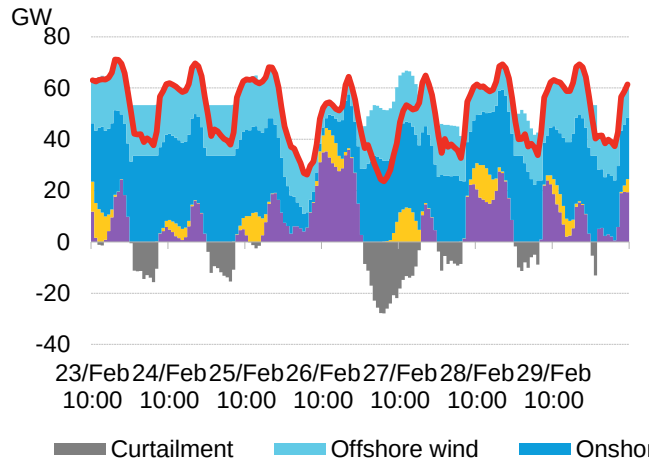
- The increase in volatility means that as early as 2030, there are whole weeks where wind and solar generation exceeds total demand at some point every day. This creates a very challenging environment for 'baseload' technologies that benefit from running at a constant stable output, such as nuclear, coal and lignite.
- This increase in volatility advantages fast-ramping technologies such as energy storage, gas generators and certain types of demand response such as flexible electric vehicle charging and variable industrial loads. Many of these resources will be decentralised in nature.
- Due to low wind/solar penetration, the Nordics do not experience significant growth in system volatility. Because hydropower is so dominant in the Nordics, a 78% renewable (11% solar and wind) scenario in 2040 is achieved without introducing large amounts of volatility and curtailment. There is still room for baseload resources that are always on.
- There is more than enough flexible hydro capacity in the Nordics to deal with the variability of wind and solar. This presents an opportunity for increased interconnection with other European countries such as the U.K. and Germany. Nordic hydro could then provide additional flexibility for those markets where wind and solar may reach much higher penetration rates.

4. The growing energy gap

By 2040, there are 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

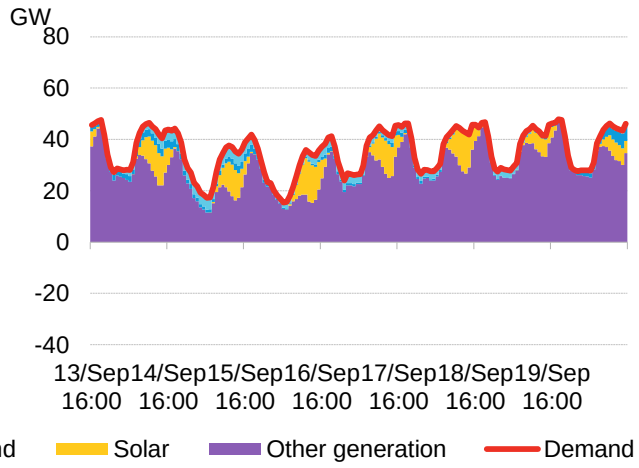
- By 2040, the highest U.K. wind and solar output week sees almost as much generation from these sources as total demand, while in Germany such generation exceeds demand. While wind and solar do not match demand in every hour, they do provide enough energy in total in these weeks, and there is opportunity for energy storage and demand shifting to help match supply and demand.
- As the timeframe increases, generation from variable renewables moves closer to the yearly average. In the highest-output month in the U.K., wind and solar generation is equivalent to 70% of demand and 78% in Germany.

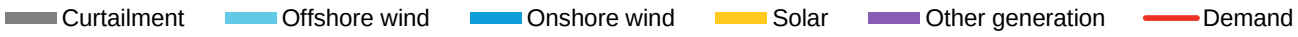
Figure 7: Highest wind and solar output week in the U.K., 2040



Source: Bloomberg New Energy Finance

Figure 8: Lowest wind and solar output week in the U.K., 2040





Source: Bloomberg New Energy Finance

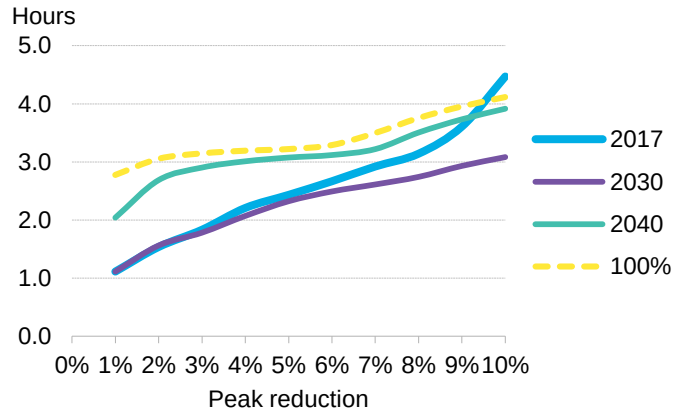
- However, there are also days, weeks and even months in the U.K. and Germany when the majority of demand must be met by other sources. There are hours with virtually no wind and solar generation in the U.K. and Germany.
- While these periods occur throughout the year, they are most common during summer wind-still periods in the U.K.. In Germany they occur during autumn and late winter, when wind is lower than in mid-winter and the sun does not shine as much as in the summer.
- The hydrological cycle in the Nordics is such that water inflow is at its lowest during winter, when water is mostly frozen, and at its highest during spring and summer, when snow melts. The opposite is true of wind power, which is higher over the winter when demand is high and lower over the summer. The complementary nature of wind and hydro makes wind a good fit for the Nordic power system.

5. The need for flexibility – at every timescale

The future energy system in the U.K. and Germany must be complemented by flexible resources – including storage. For the Nordics, there are opportunities to export spare flexibility to help plug the growing flexibility gaps in the U.K. and Germany.

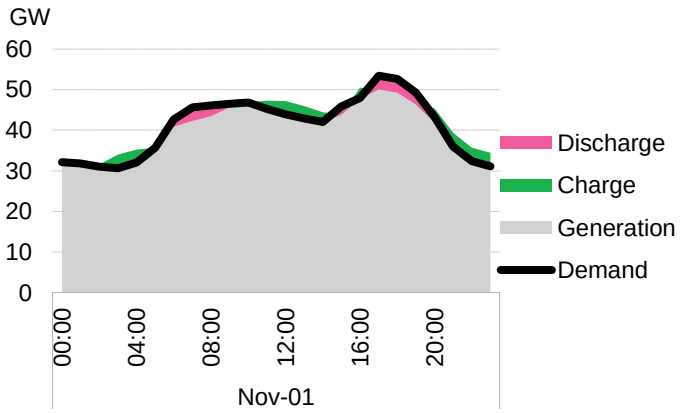
- Battery storage technologies and flexible demand are well-placed to solve short-term volatility issues arising from renewables, e.g. shifting energy from one hour to another within a day; or even shifting energy from one day to another within a week.

Figure 9: U.K. peak shaving (size of battery required in hours of storage capacity for a desired peak reduction)



Source: Bloomberg New Energy Finance

Figure 10: 5% peak reduction with battery, U.K., 2040



Source: Bloomberg New Energy Finance

- However, these technologies are not well suited to providing back-up for weeks and months when wind and solar resources are insufficient to meet demand. To meet these longer-term gaps will require dispatchable, and ideally flexible, sources. Currently, only pumped hydro, interconnectors and gas generation can do this economically. Other technologies such as hydrogen storage require significant cost reductions.
- Still, even at ~50% wind and solar, the opportunities and need for inter-seasonal storage are limited. Short-term storage provides most of the flexibility the system requires at this level of wind and solar penetration.
- In contrast, the Nordics have the flexible resources required to accommodate variable renewables – and even have flexibility to spare – thanks to Norwegian and Swedish hydropower. This presents an opportunity for increased interconnections to other European countries such as the U.K. and Germany, so that Nordic hydro can provide additional flexibility in those markets where wind and solar may reach much higher penetrations.

6. Further analysis

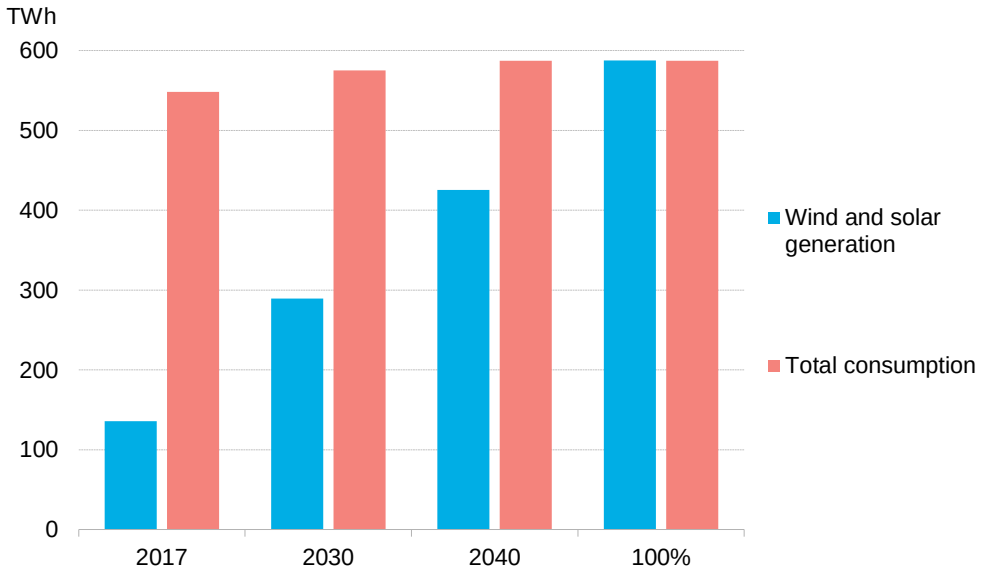
This analysis was focused on understanding the flexibility challenges that may occur after the renewables 'tipping point' is reached. Future analysis will focus on the possible solutions and opportunities, including the following:

- Opportunities for storage and flexible demand: as battery costs fall, transport becomes electrified and demand management technologies improve; these will play a larger role in energy system flexibility, complementing flexible generation. This includes both utility-scale and small-scale, decentralized sources of flexibility.
- Greater interconnection and coordination: as power markets and grids become more closely coupled, there will be greater opportunities for neighboring power systems to provide complementary support to each other.
- Power market design and policy approaches: the changes described in this report are structural and fundamental to how the power markets and grids will operate in future. Policy and regulatory approaches are already beginning to adapt, and will continue to evolve as the need for flexibility grows.

7. Scope and methodology

- For the analysis of flexibility gaps, BNEF looked at four scenarios for wind and solar:
  a. 2017
  b. 2030
  c. 2040
  d. 100%

Figure 11: Annual generation across scenarios in Germany



Source: Bloomberg New Energy Finance

- The first three scenarios (2017, 2030 and 2040) model each country's energy system with wind and solar penetrations equivalent to these respective years in the BNEF New Energy Outlook forecast. These scenarios explore what the flexibility gap would look like if the renewable deployments modelled in New Energy Outlook were to come true. The remainder of the generation stack (non-wind and solar) is simplified to a single resource which is called "other generation". This can also include other forms of renewable energy generation.
- In the fourth scenario, '100%', there is enough wind and solar generation to meet annual electricity demand. The '100%' Nordic scenario considers hydro generation as well. Demand is not met in every hour, so other resources or storage are still needed – this is not an economically modelled scenario, unlike the 2017, 2030 and 2040 scenarios which are outcomes of the New Energy Outlook. It is only included to illustrate an extreme case.

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Renewable Energy Association

The Renewable Energy Association represents renewable energy producers and promotes the use of all forms of renewable energy in the U.K. across power, heat, transport and recycling. It is the largest renewable energy and clean technology (including energy storage and electric vehicles) trade association in the U.K., with over 600 members, ranging from major multinationals to sole traders. For more information, visit: www.r-e-a.net

More information

This is a summary of the main findings, to request a copy of the full study or briefing with an analyst, please contact Eaton directly at: veragrishchenko@eaton.com

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