An introduction to weather, climate and the energy sector

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What is the energy sector?

The energy sector encompasses many types of businesses. This includes oil and gas extractors, electricity producers and financial institutions trading energy and investing in new projects. The sector is constantly evolving as new technologies are introduced, and overlaps substantially with other sectors.

One of the difficulties of producing and running weather and climate services for the energy sector is catering to this huge diversity. Different companies care about different regions, different timescales and different types of weather.

It is hard to generalise how weather and climate impacts the energy sector, but this *Insight* article will discuss some basic aspects of weather and climate forecasting for energy.

The impact of weather and climate on the energy sector

The direct impacts of weather and climate on the energy sector can be split into:

1. Impacts on energy supply
2. Impacts on energy demand
3. Effects of extreme events

Energy generation is becoming increasingly weather-dependent. Globally, over 30% of electricity produced in 2023 was from renewable sources (IEA, 2024). Wind, solar and hydro power are very weather-sensitive. Solar power has a clear diurnal cycle and requires clear skies to produce at maximum efficiency. Wind power is sensitive to wind speed at the location of the wind farm, which can be affected by local conditions as well as meso- and large-scale weather systems. Hydropower resources are affected by rainfall and drought.

These relationships are complex, and many variables are needed to accurately model energy generation. There is an approximately cubic relationship between wind speed and turbine power output up to a rated (maximum) power output, meaning power increases dramatically with wind speeds, but wind farms have a cut-off wind speed at which they must shut down for safety. See previous *Insight* articles (Sweeney, 2020; Doddy Clarke and Sweeney, 2022) for more details.

Energy demand has always been influenced by weather. At higher latitudes, total energy demand is higher in winter than summer, as homes and businesses must be heated during colder months. Closer to the equator, the opposite is true, due to summer cooling demand. Currently, some of this heating demand is met by gas heating, but as policies encourage a shift towards a fully electrified energy system (e.g. installation of electric heat pumps), the weather dependence of **electricity** demand will increase. The shift to electric vehicles and distributed generation, such as solar panels on roofs, further complicates the picture of weather-driven energy demand.

Two of the key metrics used to examine weather-dependent energy demand are heating degree days (HDD) and cooling degree days (CDD). HDDs show the extent to which the temperature is below a threshold (e.g. 12°C), and thus, heating is required. CDDs show the extent to which temperature exceeds a different threshold (e.g. 18°C), leading to cooling demand. HDDs and CDDs give a good first-order approximation for heating/cooling demand. An example annual evolution of HDD and CDD is shown in Figure 1.

Finally, energy systems are influenced by extreme weather events. Events that meteorologists typically consider 'extreme', such as powerful storms, heatwaves and floods, damage energy infrastructure and cut-off power supplies. But there are other events which impact the energy sector. This includes wind droughts: prolonged periods of still conditions that lead to low wind

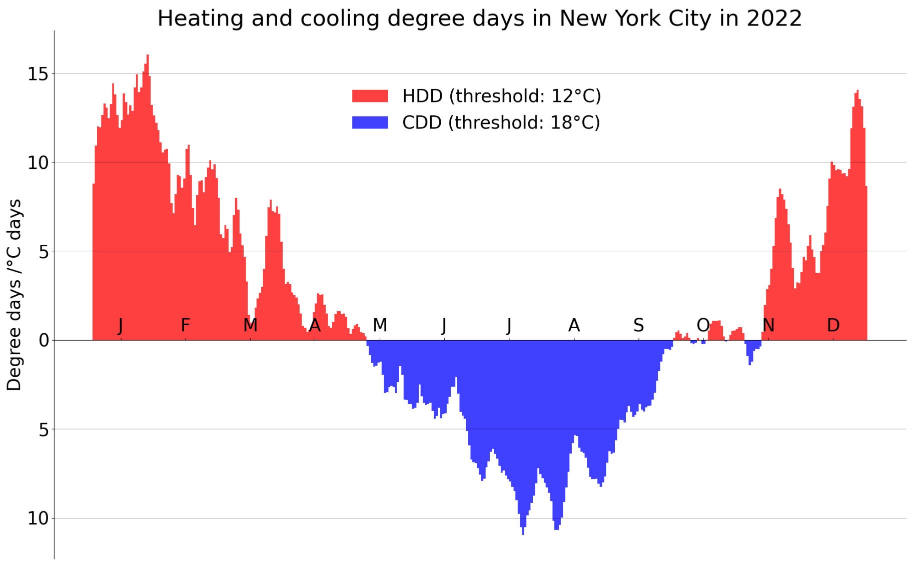

Figure 1. A bar chart showing the heating degree days (HDD, red bars) and cooling degree days (CDD, blue bars) for New York City, USA, in 2022. Thresholds are shown in the legend. CDD and HDD are calculated from daily average temperatures, and a weekly running mean is displayed. Data taken from degreedays.net. HDD are high from mid-December to mid-February, whilst CDD are high from mid-June to September. The spikes in HDD indicate cold periods with additional heating demand; peaks in CDD show heatwaves and associated increases in cooling demand.

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power production. Other areas of concern include compound events, where two or more extremes hit one after the other, or simultaneously in different locations. This puts a lot of strain on the energy system and can cost energy companies a lot of money. For example, Storm *Arwen* cost UK Distribution Network Operators (DNOs) over £44 million in customer compensation alone (Ofgem, 2022), due to network faults caused by strong winds, fallen trees and flooding at substations.

Uses of weather and climate information in the energy sector

On a day-to-day basis, energy producers and distributors use short-term weather forecasts to finely tune energy supply and predict energy demand a few hours or days in advance. This informs energy trading and ensures that enough electricity is produced from gas-fired plants to make up the shortfall between demand and renewable supply. Maintenance crews also use short-term forecasts to plan when and where to work on the electricity network.

Extreme event warnings are used by emergency response teams. This ensures that engineers can be put on stand-by to respond to network outages (e.g. blown over power lines), and that energy distributors can take anticipatory action (e.g. moving emergency generators into location).

Looking weeks or months ahead, subseasonal to seasonal forecasts are increasingly used for season-ahead energy trading, as they give broad information about whether supply and demand will be higher, lower or about the same as a typical year. In the United Kingdom, they are especially important in winter, as they help inform how much gas will be required for heating and electricity generation.

Decadal predictions and climate projections are increasingly used for long-term planning. This helps the sector respond to long-term changes in climate, by adapting and reinforcing energy production and distribution infrastructure for future extreme events. Climate projections also inform investment and policy decisions across the sector.

Additionally, the increasing share of weather-dependent generation in our energy mix requires the sector to understand natural variability and its potential impact, by carefully studying the historical record and stress-testing the energy system in different scenarios.

Forecasts are not necessarily 'ready-to-use' for the energy sector and require the interpretation and analysis of experts to become useful for energy generators, traders and planners. Energy companies require high frequency data at high spatial resolution, so there are lots of efforts to post-process and downscale climate outputs.

As climate change intensifies extremes and the sector becomes more weather-dependent, it is vital that forecasting centres work closely with energy stakeholders to develop energy sector-tailored products and ensure that weather and climate information can be effectively integrated into decision making.

Future *Insight* articles will provide more depth about how the energy sector uses weather and climate forecasts.

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Further Reading

These companion papers contain more information about many of the topics discussed here, including the impact of weather and climate on energy, and how the energy sector is adapting to climate change.

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There is also a variety of data available from NASA, the Copernicus Climate Change Service, national meteorological services and academic institutions which is useful to the energy sector.

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