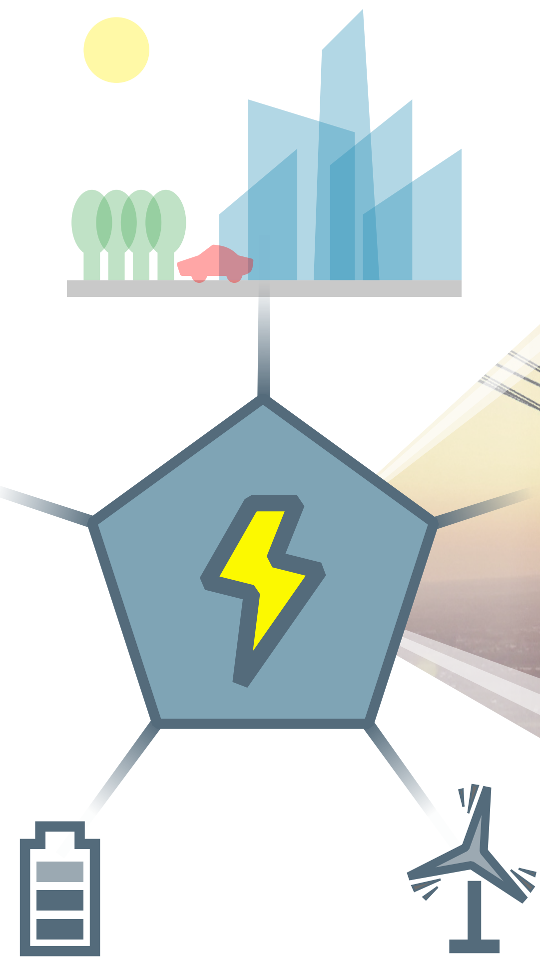
From Power Stations to Houses

A Brief Overview of the Electricity System in Great Britain



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e4Future

e4Future is an Innovate UK-funded project brings researchers, car manufacturers and power system stakeholders together in a unique collaboration. Dr Myriam Neaimeh leads Newcastle University's activities on the project. The project aims to encourage significant take up of Battery Electric Vehicle (BEV) in the coming decade by lowering the cost of ownership of these vehicles and providing services to the power network. The Vehicle-to-Grid chargers allow bi-directional power flows between BEVs and the network and are controlled by an innovative aggregator platform. This aggregator platform aims to benefit BEV users by lowering vehicle operation costs and by supporting a more efficient electricity network. Project partners are:

Newcastle University · NISSAN · UK Power Networks · Northern Powergrid · nationalgridESO · e.on · Imperial College London

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1 The structure of power grid in the UK

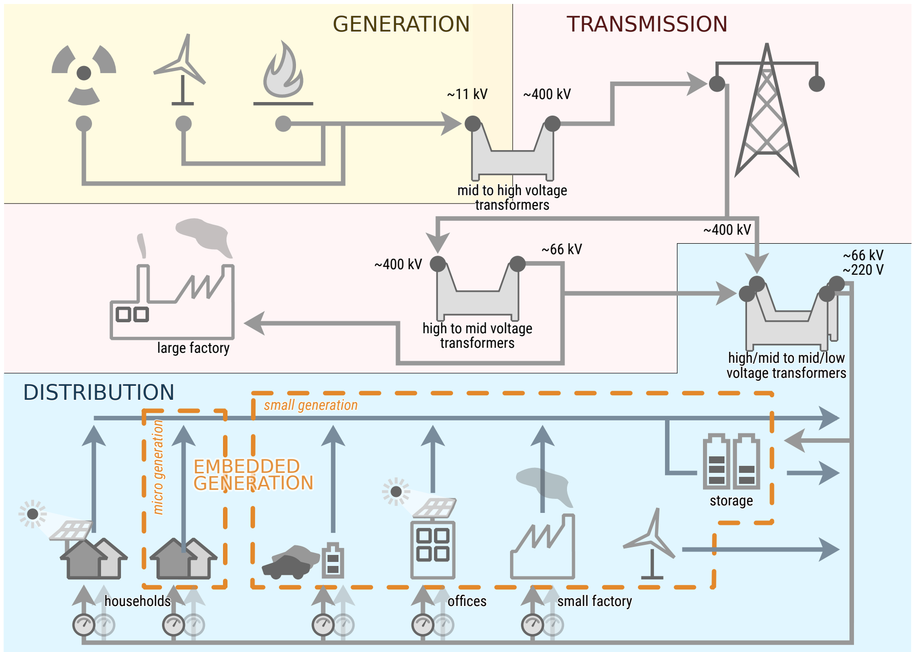
Every day, a colossal amount of electrons flow through our appliances that demand energy. The complex network of interconnected cables that allows energy to flow from suppliers to consumers is called the **power grid**. Consumers of energy are of two types, either large factories or homes and companies. Before reaching the consumers, the energy needs to be generated, transmitted, then distributed, all under some regulation toward safety, security and reliability. The Figure 1 on the following page illustrates the structure of the power grid in the UK, where the *embedded generation* is what started happening and it must be better regulated in the near future.

1.1 Generation

The electricity we consume originates from several sources (sunlight, gas, water, coal, and others) that power stations are able to convert to electricity, with some efficiency ratio[1]. Energy loss at the generation phase is not counted in the energy loss of the power grid, as their nature changes by the source and the methods. Renewable energy sources has been increasing in the last decades at the generation level; however, their instability in the supply of power makes balancing more difficult [5]. Balancing the supply and the demand is particularly important to keep the frequency of the current at the statutory level of 50 Hz; if the frequency deviates too much from this value, automatic actions are taken, from speeding up the generation frequency to disconnections of demand.

[1]This is due to the transformation of energy of one type to electrical.

Figure 1.1: Structure of the power grid in the UK (inspired from [3]).



1.2 Transmission

Generators and consumers are usually very far away and the energy needs to *travel* before being distributed to the consumers. The infrastructure to do that is called **transmission**. Physics teach that energy *travelling* through high voltage cables is more efficient in terms of the (inevitable) power loss that the journey itself obliges. Therefore, the transmission, either overhead or underground, is generally very high voltage, e.g. 400 kV.
Sometimes a *main* substation is connected to both factories and other substations with high voltage cables, e.g. 66 kV. This lower voltage, in comparison to that from power stations to substations, causes only slightly higher a loss as the cables are much shorter. The transmission comprises, at one end, the power stations (excluded) and, at the other end, the *leaf* substations (excluded). When energy is sold or bought from another country, the transmission crosses a political boundary. The transmission itself can be virtually partitioned in areas, e.g. North East and Scotland, through whose boundaries energy can flow up to a physically determined limit. Currently in the UK, embedded small and medium power stations are not required to be the subject of an agreement with the system operator (NationalGrid) and are

not required to participate in the balancing mechanism, whereas embedded large power stations are [9]. So the transmission operator may be unaware of what happens behind the transformer attached to a distribution node[2].

1.3 Distribution

Once the energy *travelled* close enough to the consumers, the process of *moving* the energy from the substations to companies and houses is called **distribution** of energy. The power is not directly supplied to our houses because the voltage out of generators is too high, e.g. 11 kV, and can put in severe danger our lives. Therefore, the voltage has to be *transformed* to be suitable for the domestic typical usage, e.g. 220 V, or for the usage of industrial consumers (large factories). Distribution can actually count their own substations in charge of this transformation. The amount of energy consumed by a house is metered. The very final bit of the grid that brings the energy from the power meters to the sockets in the house and finally to our appliances does not belong to the distribution. If substations are one end of the distribution, then power meters (included) are the other end.

1.3.1 Distributed Electricity System

Small and local power stations can be directly connected to the distribution network [3]. Notably, along with power stations, storage systems [11] can be figuratively considered at the generation level. In practice, their connection to the grid may be close to the distribution and able to serve part of the demand, configuring the grid as an effectively distributed electricity system. Another use of storage systems is to stabilise the network to compensate for fluctuations caused by renewable energies. An important point is that embedded generation is at the distribution level and is not necessarily behind the meter, but all that is behind the meter is considered as embedded generation. Embedded generation is *invisible* to the national grid (the transmission operator), but they need to predict the demand to do investments.

[2]Craig Lowray (Cornwall Insights) during the GB Electricity Market Course.

2 | Who does what

The power grid counts numerous players with similar or different tasks, goals, and responsibilities that can be referred to the structure of the grid itself. They change through time due to political restructuring or advances in technology and society.

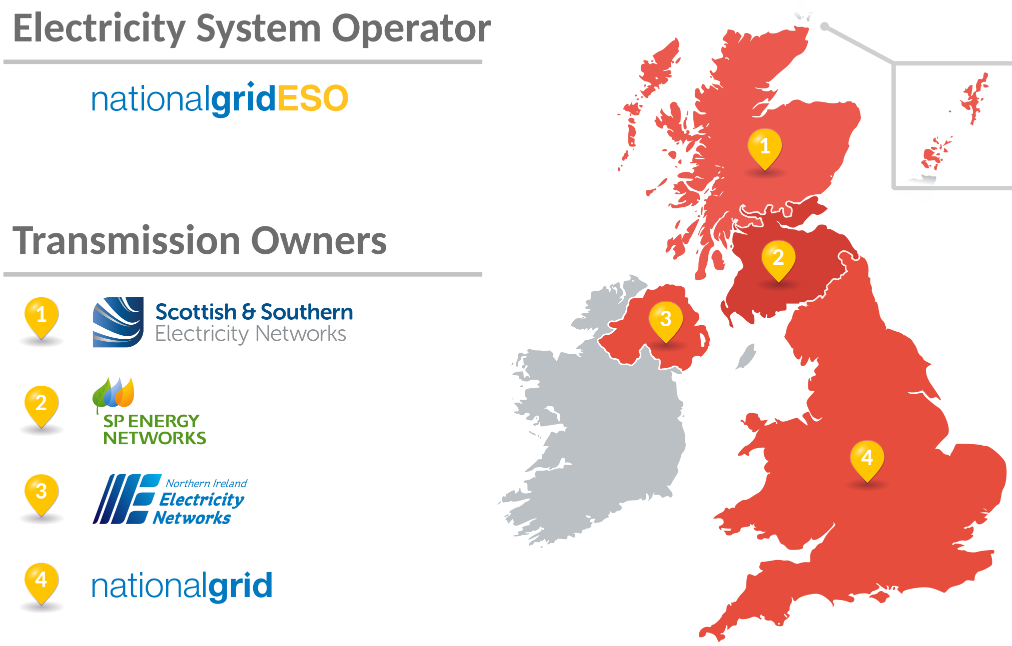
2.1 Generation

Currently at the generation level, the six major companies dominating the British electricity market are: EDF Energy, British Gas, E.ON, Npower, Scottish Power and Southern, and Scottish Energy (SSE) [1].

2.2 Transmission

The electricity transmission counts four operators, *NationalGrid* in England and Wales, *Northern Ireland Electricity Networks* in Northern Ireland, and *SP Energy Networks* and *Scottish and Southern Electricity Networks* in Scotland [8], see Figure 2.2. To avoid conflict of interests, the infrastructure is not owned by the transmission operators, but by a separate company, called the Energy System Operator, *NationalGridESO*. Transmission operators have a role in continuously balancing generation and demand, to secure the security of the network. In practice, they[3] (i) monitor and manage voltage and frequency response, (ii) provide spare capacity to mitigate failures in generation or demand predictions, and (iii) ensuring the availability of generating units in the event of a catastrophic failure of the network and complete power loss.

Figure 2.1: Energy Transmission in the UK (adapted from [8]).



2.3 Distribution

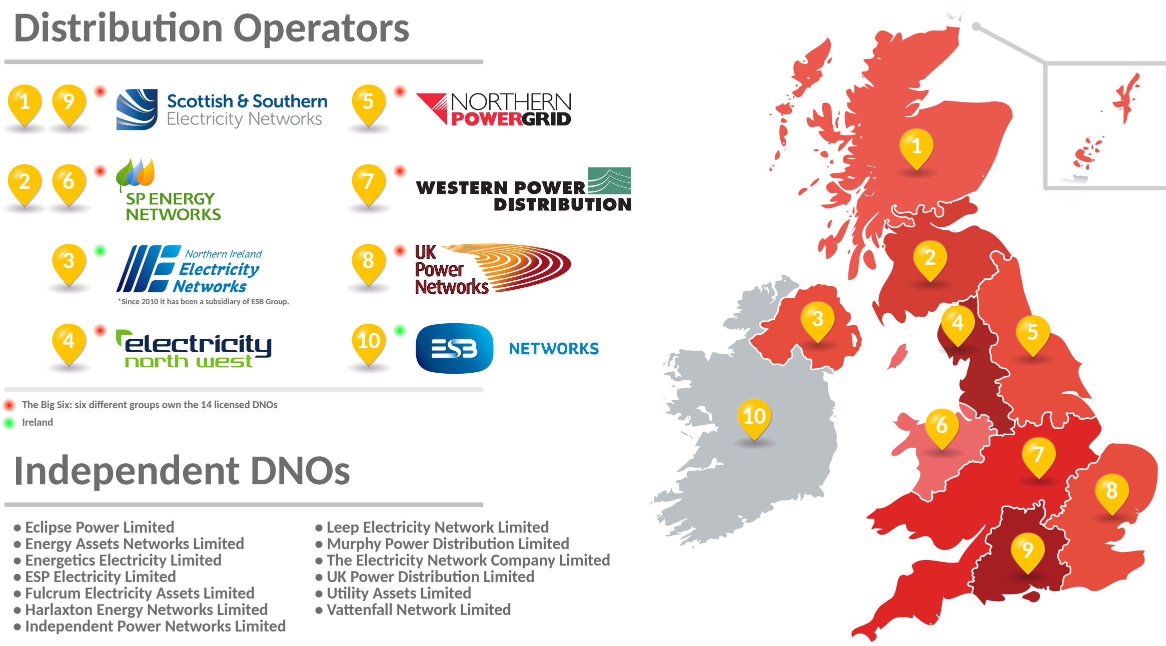
All distribution sub-networks are managed by **D**istribution **N**etwork **O**perators (DNO) licensed by the UK government [7], see Figure 2.2. DNOs are responsible to provide secure, reliable and high quality electricity, as well as it must facilitate competition in generation and supply (and they cannot supply). They cannot sell energy to customers, but they are responsible to bring the energy up to their meters. Behind the meter, suppliers are the companies that finally make contracts with home customers and provide them bills, e.g. E.ON or SSE [2]. So residential customers are directly in touch with DNOs for the infrastructure, but are billed by suppliers[1].

2.4 Regulation

The Department of Business, Energy and Industrial Strategy set the policy of both transmission and generation, and decides the rules that they have to be compliant with. Once the policy is established, it is implemented by the

[1]A sample rate on a house bill for electricity can be around 16 pence per KWh of energy consumed.

Figure 2.2: Energy Distribution in the UK (adapted from [7]).



Office of **g**as and **e**lectricity **m**arkets (Ofgem). In particular, Ofgem regulates the network, the market and the prices, protects domestic and business customers. One important aspect to remark is that the NationalGrid as electricity system operator (ESO) takes control of the market before delivery to manage the system (balancing mechanisms are used to derive imbalance prices and contracts).

3 | The future of the grid

The grid is experiencing the need for changes due to the advance of technology and society in the UK, and its future is yet to be decided but towards a *smart grid*. This is in accordance to recent plans of the government [12], aiming to provide incentive and start a transition to a zero-emission society, where electric cars over the oil-engine are an important part of the whole picture. Historically, those transitions are unlikely to be quick, and the politics and economics around it are changing and yet to find regulations. With little more details, the smart grid brings further energy generation sources directly attached at the distribution level, e.g. smart buildings and electric vehicles. Their initial idea is to borrow from the regulations already in place for smart meters, adapting those to the more challenging aspects of how the smart grid is becoming.
Another crucial aspect is at the power station level. In fact, the current electricity generation mix scenario [10] (see Fig. 3 on the next page) is experiencing a significant change as we move towards using less carbon intensive fuel sources. This change affects the price for producing the energy [6] in the market, which will reflect to the bill costs that household will receive. Moreover, it affects the network as balancing becomes harder to maintain than in the past [5].
On the other hand, the demand is also expected to change. The demand in a household is forecast to increase as illustrated in Figure 3 and 3. The demand is therefore expected to increase significantly. As we can see from the figures, the local generation, i.e. solar panels, is expected to increase, but not as much as the consumption of energy. As electric vehicles are not (yet) currently contributing, if not marginally, to the electric usage, the graphs above [4] do not take into account the intake of the vehicle-to-grid (V2G) technology. Another consideration is that, in comparison to V1G, the

Figure 3.1: Electricity generation mix by quarted and fuel source in the UK [10].

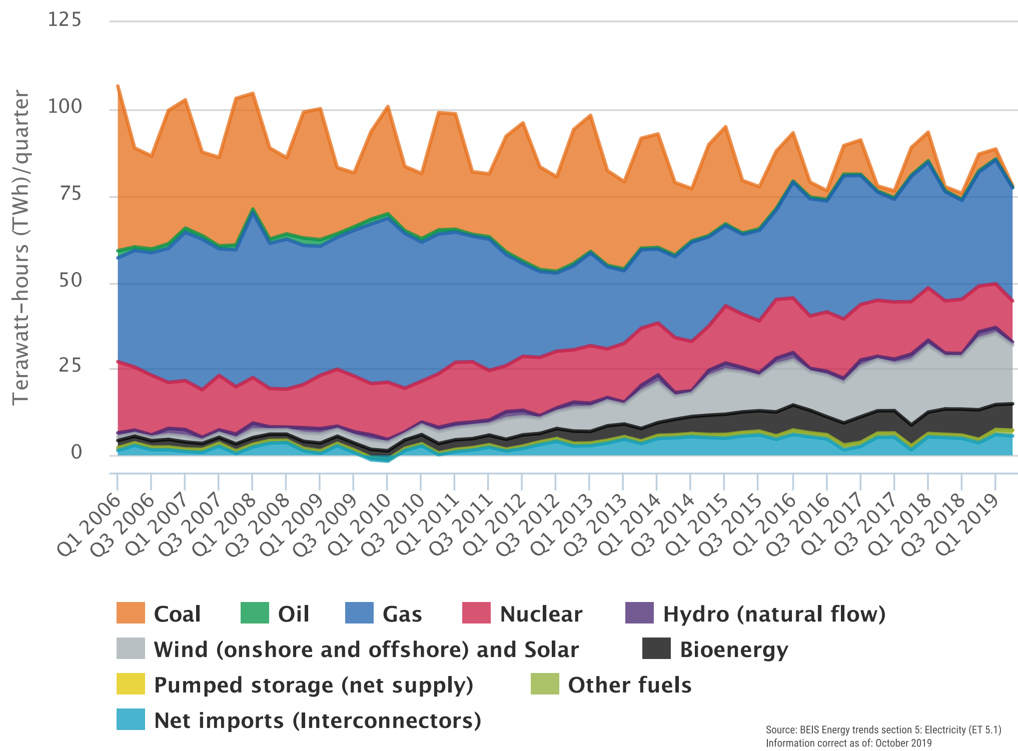


Figure 3.2: Forecast average daily electricity demand from domestic consumers, under the Department of Energy and Climate Change High Uptake Scenario compared to the 2010 Household Electricity Usage Study monthly averages [4].

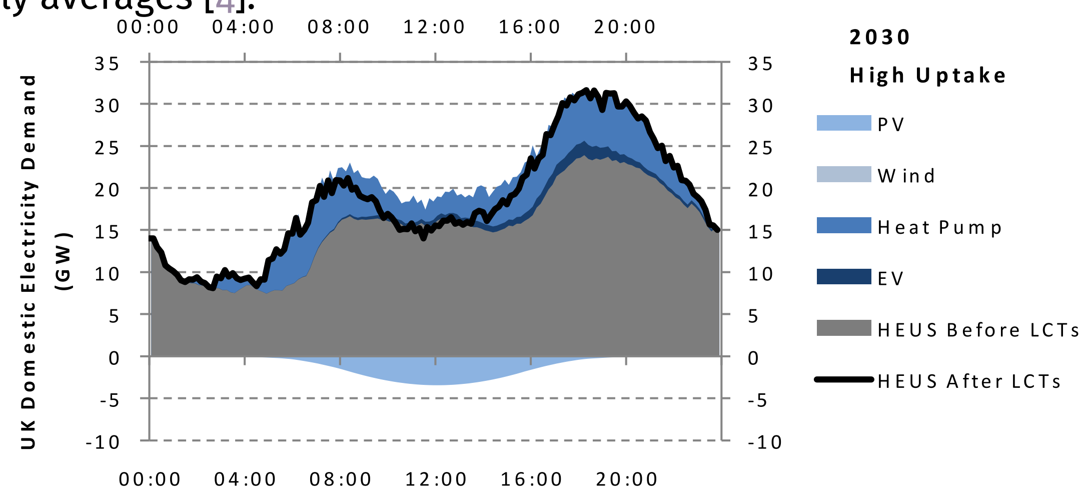
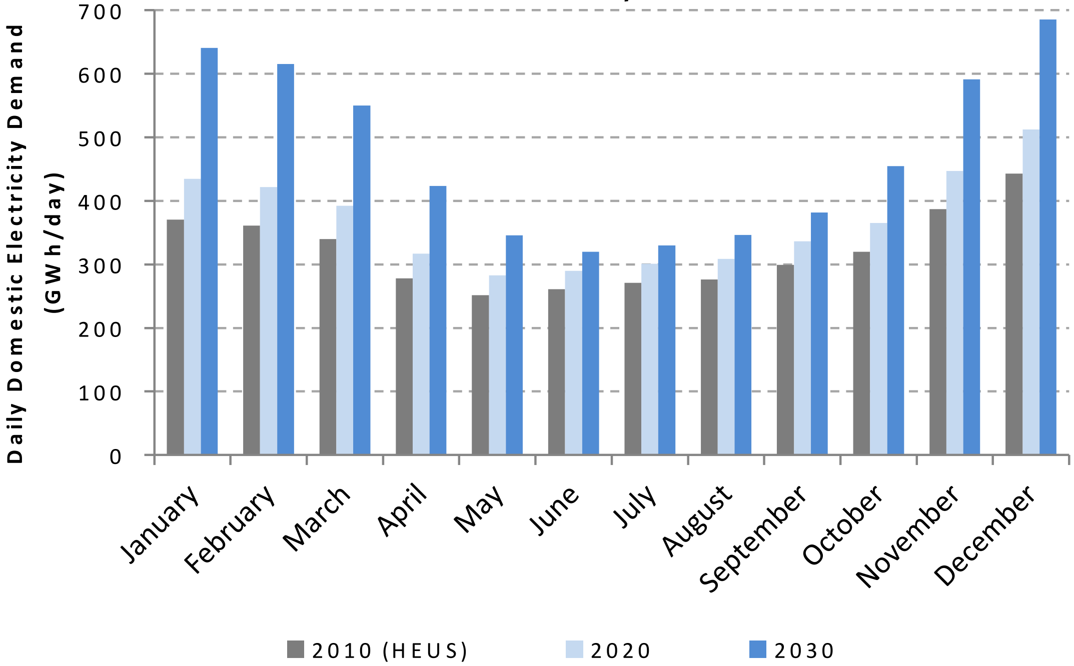


Figure 3.3: UK annual average electricity demand and generation profiles for the Department of Energy and Climate Change Low, Central and High Uptake Scenarios in 2030, with no demand side response [4].



V2G should not inherently increase or decrease the average demand, but it can be used to help distributing energy when required, not only to avoid peaks in the demand.

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