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Energy security

Energy security concerns have risen over the last year, brought about by high international gas and electricity prices, and the possibility of gas shortages during winter 2022.[1–6] This POSTnote examines the risks to the UK's energy security, current practices for ensuring energy security, and measures that might be taken to enhance energy security as the UK transitions towards a net zero economy.

Overview

- Definitions of energy security can include the availability of fuel, affordability, environmental and geopolitical acceptability, and accessibility of energy.
- Energy security risks include high energy prices, fuel shortages, equipment failures, the effects of climate change and net zero transition risks, such as a lack of investment or system operability challenges.
- Great Britain's energy security processes and metrics focus on electricity generation, and the reliability of gas and electricity networks, ignoring the price of energy.
- Measures to improve energy security include demand reduction, energy storage, diversification of supply, energy market reform and interconnection, but will not provide short-term energy price relief.

Background

Recent international energy price rises have raised serious concerns about the ability of households and businesses to pay their energy bills.[7,8] Doubts about the availability of Russian gas supplies following the invasion of Ukraine have renewed interest in energy security (CBP 9544).[9,10] Energy security issues in Great Britain (GB) over the last four decades have mostly been due to storms.[11–14] The last significant energy supply crises occurred in the 1970s with global oil shortages and coal miner strikes.[15,16]

Rising prices are affecting every form of energy for both business and domestic customers. The default tariff cap, a limit on household gas and electricity bills, will rise to £3,549 in October 2022, a 178% increase from a year before, with further increases expected after that.[17–19] An Office for National Statistics survey in June 2022 reported that 37% of respondents in GB are struggling to pay their energy bills.[20] To provide short-term relief, the Government announced a package of measures for households.[21] There have been calls for the Government to provide significantly more support.[22]

The British Energy Security Strategy, published in April 2022, sets targets for additional renewable and nuclear electricity generation, and oil and gas developments.[23] The Strategy was widely criticised for ignoring measures that could help reduce bills more quickly, such as energy efficiency.[24–30] The Energy Bill, introduced in July 2022, will legislate on a number of longer-term energy security issues, including establishing a new Independent System Operator and Planner, responsible for strategic planning of the gas and electricity systems (LLN 2022-0030).[31–33]

The gas and electricity systems in GB and Northern Ireland (NI) are independent. NI is part of an all-island energy market with the Republic of Ireland. Where possible this POSTnote provides information for the UK. However, information is frequently only given for GB due to the differences between the two systems.

For the purposes of this POSTnote, short term is the next 2 to 3 years, before substantial infrastructure changes can be made. Medium term is 2030–40 when the bulk of the net zero energy transition will be delivered. Long term is from 2050 onwards once the net zero transition has been completed.

Components of energy security

There is no agreed energy security definition.[34] A commonly used definition from the International Energy Agency is 'the uninterrupted availability of energy sources at an affordable price'.[35] Definitions often include some combination of *availability*, *affordability*, *acceptability* and *accessibility*:[36–40]

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- *Availability* of energy means sufficiency of supply, and is at the core of most energy security definitions.[34] Availability includes ensuring sufficient supplies of directly generated electricity (renewables, nuclear) and oil and gas, including the refining capacity to convert crude oil into useful fuels.[41]
- *Affordability* of energy means the ability to pay for energy.[42] Affordability issues may prevent customers from obtaining energy, even if it is physically available.[43]
- *Acceptability* of energy relates to wider policy considerations.[44] For example, the UK Government decided to end coal power generation by October 2024 for sustainability reasons and decided to stop Russian oil and gas imports as soon as practical for geopolitical reasons.[45,46]
- *Accessibility* of energy means having the infrastructure required to move energy to where it is needed, including the capacity and reliability of electricity and gas networks.[37]

Security of demand for energy can be as important as supply in certain contexts. A consistent international demand for energy is important for countries that export energy as a significant part of their economy.[41] Certainty over future demand is also important for those investing in energy infrastructure, which often has long life spans and pay-back periods.[47]

Energy security risks

Risks to energy security, and their potential mitigations, vary depending on the timescale under consideration. The UK uses energy, primarily from renewable electricity, nuclear power, natural gas and oil derived liquid fuels, to meet its demand for heating, transportation and power.[48] The most important factors in the short term are likely to be the supply and price of the types of energy the UK currently uses.[49–51] In the longer term, the energy system will change, altering the risks to energy security.[52] Transitioning to a net zero carbon energy system is likely to change the energy security risks the UK faces, as the fuel mix, demand and types of companies involved in the energy system change.[53] Short-term decisions will play out slowly because infrastructure has long construction periods.

High energy prices

The energy security challenges experienced in the UK and Europe since 2021 have, to date, resulted in high gas prices rather than a physical shortage of supply (affordability rather than availability or accessibility).[43] Box 1 explains this unprecedented spike in the wholesale gas price. The electricity price in GB is highly correlated with the gas price due to the way the electricity market was designed.[54–56] A review of energy market arrangements, launched by BEIS in August 2022, is considering options to decouple the gas and electricity price, amongst other things.[57]

High energy prices have been a major driver of the 'cost-of-living crisis'. There is evidence of consumers self-rationing their energy use.[58] Rates of self-disconnection of pre-payment meters (choosing to turn off gas and electricity supplies to avoid paying high costs) reported to Citizens Advice have risen eight-fold in the last year.[59,60] The situation shows no sign of easing. Consumer energy prices will rise again significantly in October 2022 and January 2023.[18,19] Business electricity and gas rates are not regulated by the default tariff price cap, and may double in October 2022 compared to last year (CBP 9491).[72] Ofgem, the GB gas and electricity regulator, has received significant criticism for not sufficiently protecting customers.[73]

Box 1: 2021–22 European gas price crisis

Gas prices in the UK and Europe have been at unprecedented high levels since the second half of 2021.[1,61] The initial price rises were due to a range of factors including increased demand for liquified natural gas (LNG) as Asian economies reopened after COVID, and a lower gas supply to Europe from Russia.[62–64] Large gas storage facilities in Germany and Italy did not fill to capacity during the spring/summer of 2021 because of these high prices.[65–68]

The shortage of gas during winter 2021 was filled by higher year-round LNG imports, where Europe usually imports much more LNG during the summer than winter.[63,69] This increase in European LNG demand, coupled with rising LNG demand in Asia, led to high LNG prices and hence high gas prices.[70]

Russia's invasion of Ukraine caused further instability in Europe's gas supply, sustaining high prices throughout 2022.[1,61] Russia restricted gas flowing to Germany through the Nord Stream 1 pipeline to 40% of its normal volume in June 2022, and again to 20% in July 2022.[6] Large gas storage facilities in Germany were just over 76% full in mid-August 2022.[68] It is uncertain what Nord Stream 1 volumes will be for the rest of 2022 and if German gas storage facilities will reach their 95% target by November 2022.[71]

Liquid fuel prices have also risen significantly. Petrol and diesel prices are at an all-time high, up over 30% in the first half of 2022 (SN 4712).[74] Fuel oil, used to heat 68% of homes in NI, has risen in price two and a half times in a year, and has historically experienced very volatile pricing.[75–77]

Fuel shortages

Russia might continue to restrict the supply of gas to Europe, which could lead to physical shortages if gas storage facilities are not refilled before winter.[78] Gas demand is highly weather dependent because a high proportion is used for heating.[79] Whether or not there is a shortage of gas over winter 2022 could depend on how cold the winter is, and how successfully EU countries meet their 15% gas demand reduction target. This was introduced following Russia's reduction in gas exports to Europe.[80,81] The UK has not set any comparable targets.

Gas shortages in Europe could lead to prohibitively high prices, or physical shortages in the UK. In winter, the UK normally imports gas from Europe.[82] Likewise, Europe imports gas from the UK during summer to help fill large gas storage facilities while UK gas demand is low.[82] In the event of a gas shortage, the EU has contingency plans in place to stop these cross-border flows.[83] The UK has modelled this scenario, but stakeholders feel that it is highly unlikely to play out in practice given the high level of interdependence between GB, Ireland and mainland Europe.[84,85] Since autumn 2021, GB has maintained a secure supply of gas by paying for expensive liquified natural gas (LNG), mainly from the US and Qatar.[86,87]

Although fuel supply shortages are rare in developed counties, Russia's restriction of gas to Europe shows that geopolitical events can cause fuel shortages and high prices. Physical shortages of energy are not a problem the UK has had to deal

with in the recent past. Petrol and diesel shortages caused by protesters blocking oil refineries in September 2000, and the shortage of HGV drivers in 2021, were distribution issues.[88,89] However, the UK's reliance on a global market for fuel opens up the risk of geopolitical and economic supply disruptions.[84]

Equipment failure

Failures of transmission, distribution, generation and other energy infrastructure are the most common causes of inability to deliver electricity to consumers (failure of accessibility).[90] Historically, many failures of the UK's electricity systems have been related to extreme weather events. For example, Storm Arwen in November 2021 led to over one million customers losing power.[91] Around 40,000 customers were without power for more than three days, and around 4,000 customers were without power for over a week.[91]

Multiple simultaneous failures, or cascading failures, can worsen the effects.[92] For example in August 2019, a lightning strike on the electricity transmission network, and a series of knock on events including the failure of two large generators, caused power loss to over one million customers in southern England.[93,94] The system was restored within 45 minutes, but disruption to the rail network lasted longer.[93–95]

Failures of equipment outside the UK can also have a significant effect on UK energy security. A fire at the Freeport LNG facility in the US in June 2022 caused a complete loss of supply from the facility, which processes 20% of US LNG exports.[96] Partial restart of the facility is expected in September 2022, with full export expected to resume by the end of 2022.[96] The US supplies around 26% of the UK's LNG imports.[86]

Equipment failures can impact whole classes of equipment. Following the discovery of cracking in a safety system in the French Civaux No. 1 nuclear reactor, three other reactors in Civaux and Chooz were also shut down for precautionary inspections.[97] Since all four reactors use the same design there is a risk that the fault in Civaux No. 1 might be common across all four reactors.[97]

Effect of climate change

Climate change will impact the UK's energy security. The UK's Independent Climate Change Risk Assessment has predicted that severe weather events, such as flooding, will increase the risks to energy infrastructure (PN 621).[98] Extreme high and low temperatures can cause failures in electricity transmission and distribution systems, and cause operability issues due to high demand.[98] For example, during the July 2022 heatwave, National Grid paid 5,000% of the typical price to keep the system stable.[99] Droughts in Norway during August 2022 severely limited hydroelectric generating capacity, jeopardising electricity exports to the UK.[100]

Decisions taken for short-term energy security can have wider detrimental consequences for long-term energy and climate security because of climate change (PN 680).[101] Proposals to issue new oil and gas licences in the North Sea are seen by the Government as a means to increase medium-term energy security by providing more secure supplies of oil and gas.[23,102] In the long term, the extreme weather and temperatures caused by climate change may make the energy system less reliable if it is not adapted to cope with them.[98,103,104] There is a growing body of evidence on the need for oil and gas reserves to remain in the ground to limit global temperatures rises to 1.5°C above their pre-industrial average, as per the Paris Climate Agreement.[105,106] New oil and gas licencing rounds will not improve energy security in the short term because of the long construction times of new infrastructure.[107,108]

Energy transition risks

The mix of energy used in electricity generation, heating and transport is likely to change significantly over the coming decades to meet the carbon budgets introduced under the Climate Change Act 2008.[109–111] Demand is expected to move from carbon intensive sources, such as gas for domestic heating and petrol and diesel for most vehicles, to electricity or hydrogen.[109,110] At the same time, it is likely that the proportion of electricity generated from variable renewables and non-flexible nuclear power will increase, creating new challenges balancing the supply and demand for electricity.[109,110] This shift in energy generation and demand is likely to improve energy security in some respects, such as reducing reliance on volatile international gas markets, while creating other new risks.[112] Some new risks are transition risks that will only exist while the energy system changes. Others are likely to persist:

- *Electricity system operability* – The reduction in flexible generation, coupled with higher electricity demand, is likely to create operability challenges for the UK's electricity system. Gas turbines are currently used as a flexible source of electricity generation that can balance between renewable and nuclear electricity generation, and demand.[113] As the electricity system is decarbonised, other sources of flexibility, such as energy storage, will be required (PN 587).[114]
- *Loss of diversity* – Energy customers typically use a range of energy sources to meet their needs.[50] For example, gas for cooking, electricity for household appliances, and petrol or diesel for transportation.[50] This diversity of energy carriers provides some resilience if one fails, such as in the event of a power cut.[115] If more energy demand is electrified, reliance on the electricity system may lead to a loss of resilience.
- *Insufficient investment* – In order to meet a higher demand for electricity, and potentially a new demand for hydrogen, significant investment in electricity and hydrogen generation and networks will be required.[116–118] Projects to build new generators and improve networks are capital intensive with long lead times. Supply chains need a stable stream of investment and contracts to build their capacity.[119]
- *Lack of workforce skills* – In order to build the infrastructure required for the energy transition, many skilled workers will be required.[118,120–122] Industry stakeholders raised significant concerns about the potential lack of suitable workers.[120,121]
- *Access to critical materials and minerals* – Renewable sources of electricity are not dependent on access to fuels, but do require materials and minerals that the UK does not have a domestic supply of (PN 609).[106,123] The Government's recent Critical Minerals Strategy considers these issues.[124]
- *Cyber security risks* – Cyber-attacks on energy infrastructure are likely to become a greater risk during the energy transition (PN 554).[125,126] There have been examples of cyber-attacks being used to disable electricity systems. For

example, a cyber-attack on the Ukrainian electricity system in December 2015 left around 225,000 customers without power for up to six hours.[127] The energy transition could increase the cyber security risk because of digitalisation of demand and an increase in the number of generators.[125,126]

Metrics of energy security

Measuring energy security is crucial to its management. Since energy security is poorly defined, it is difficult to measure. The metrics used in GB focus narrowly on the operation of the electricity and gas systems. There are no energy security metrics for liquid fuels. None of GB's energy security metrics cover diversity of supply, level of investment or affordability.

For electricity, the main metric of energy security is loss of load expectation (LOLE).[128] LOLE is the number of hours a year where there is a shortage of generation relative to demand and the system operator must take extraordinary measures to keep the system operating normally.[128] The LOLE limit for GB is 3 hours per year, but the actual figure is normally well below this.[129] The estimate for winter 2022 is 0.1 hours per year.[130]

The gas system is harder to restart than the electricity system leading to a more stringent security standard. The gas system is designed so that its capacity would be exceeded in one out of 20 winters.[128] Box 2 explains the processes used in GB to ensure that these security standards for the gas and electricity systems are met. Like the metrics of energy security, the processes are narrowly focussed on ensuring there is sufficient electricity generation, and that the gas and electricity networks are reliable.

Measures to improve energy security

Maintaining an energy system that is operable, reliable and affordable is a complex challenge. A range of measures could potentially be taken to improve energy security. Stakeholders stress that with all these measures, clear and consistent policy backed up by long-term contracts is crucial to allow people to retrain and supply chains to invest in building capacity.[119–122]

Demand reduction and flexibility

Demand reduction is consistently identified as a fast, cheap and effective way of increasing energy security, but has been neglected by the Government in favour of supply side measures (PN 550).[131–133] The most secure unit of energy is a unit you do not need. Energy efficiency improvements since 2004 are estimated to have saved the average household £500 a year.[134] However, almost 60% of homes in England and Wales have an Energy Performance Certificate (EPC) rating below C.[135] It is estimated that bringing all the homes in the UK up to EPC C standard could save the equivalent of six nuclear power stations in demand, and the aggregate bill savings would be £10.6bn per year at a relatively modest upfront cost.[136,137]

Digitalisation could provide an opportunity for demand to play a greater role in balancing supply and demand for electricity in place of gas turbines, helping to decarbonise the electricity system (PN 655).[112,138,139] This would require widespread installation of new control and instrumentation equipment, including smart meters (CBP 8119).[140]

Domestic energy generation

Increasing domestic supplies of energy can reduce availability, accessibility and acceptability risks by reducing reliance on imports from other countries. The British Energy Security Strategy focuses on domestic energy generation measures, which include targets to increase the amount of wind, solar and nuclear electricity generation in the UK, and proposals to exploit more oil and gas reserves in the North Sea.[23]

Stakeholders have differing views on the role of new oil and gas developments in energy security. Although they can reduce reliance on imports, the UK's lack of gas storage facilities limits the benefits of new North Sea gas production. Additional North Sea oil production would not have a substantial effect on energy security because 83% of UK oil is exported.[48–50]

Energy storage and interconnection

Energy storage can reduce volatility in energy prices and make up shortfalls in supply. GB can currently store five days of peak gas demand.[141,142] The limited gas storage capacity in the UK means that it must balance production, demand and imports/exports. GB had a larger gas storage facility, Rough, which closed in 2018.[143] Following high gas prices during 2021-22, Centrica is working to recommission Rough.[144,145] Energy storage technologies, such as batteries or hydrogen, are likely to play a larger role as the energy transition progresses. More energy storage will be necessary to replace the flexible generation role currently provided by gas turbines.[146–148]

Increasing interconnection between countries' electricity networks increases diversity of supply and demand, helping to balance intermittent renewables (PN 569).[149] This is likely to lead to a reduced overall cost for a zero carbon system.[150,151]

Box 2: Processes for securing energy supplies

Energy security processes in GB look forward over a number of years to ensure there is sufficient generating and network capacity. The Capacity Market (CM) is used to procure electricity generation:[152]

- National Grid ESO produce Future Energy Scenarios which examine future electricity generation requirements.[109]
- The Secretary of State for BEIS decides how much electricity generation to procure to keep the LOLE below 3 hours per year.[152]
- National Grid ESO procures the generation at the lowest cost offered in the CM auction.[152]

Gas and electricity network operators are responsible for ensuring their networks meet reliability standards.[153,154] Network operators apply to Ofgem for investment in their networks, with costs added to customers' bills.[155]

Each year, National Grid ESO and Gas Transmission produce winter outlooks for the gas and electricity systems.[156,157] These outlooks examine the excess supply margin compared to peak demand for the winter.[156,157] Based on these outlooks, the system operator will take actions to ensure there is sufficient capacity, such as notices to generators asking them to be available during predicted shortages, or using the balancing mechanism to procure generation.[153]

Emergency exercises are carried out by the government, regulator and industry to assess the readiness to deal with extreme events such as storms and cyber-attacks.[158,159]

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References

1. Intercontinental Exchange UK Natural Gas Futures.
2. EPEX Spot Market Data.
3. Nord Pool N2EX Day Ahead Auction Prices.
4. Ofgem Wholesale market indicators.
5. Acreman, M. *et al.* (2022). REPowerEU and the Short-Term Outlook for the European Gas Market. Oxford Institute for Energy Studies.
6. Nord Stream AG Network Data.
7. Kollewe, J. (2022). Rising energy bills and staff shortages driving UK companies into insolvency. *The Guardian*.
8. Butler, S. (2022). More than one in eight UK households fear they have no way of making more cuts. *The Guardian*.
9. International Energy Agency Russia's War on Ukraine.
10. Benton, T. *et al.* (2022). The Ukraine war and threats to food and energy security. Chatham House.
11. BEIS (2021). UK Energy in Brief 2021.
12. National Grid Electricity Transmission (2021). Our Performance 2020/21.
13. National Grid Gas Transmission (2021). Our Performance: 2020/2021.
14. National Grid ESO (2021). National Electricity Transmission System Performance Report.
15. The National Archives Global oil shortage.
16. The National Archives British Economics and Trade Union politics 1973-1974.
17. Ofgem (2021). Default tariff cap update from 1 October 2021.
18. Lowrey, C. (2022). Price cap forecasts for January rise to over £4,200 as wholesale prices surge again and Ofgem revises cap methodology. Cornwall Insights.
19. Ofgem (2022). Default tariff cap level: 1 October 2022 to 31 December 2022.
20. Office for National Statistics (2022). Public opinions and social trends, Great Britain.
21. BEIS (2022). Energy Bills Support Scheme explainer.
22. National Energy Action (2022). Supporting vulnerable energy customers through the energy crisis.
23. HM Government (2022). British Energy Security Strategy.
24. Vowles, N. (2022). Energy security strategy analysis: Huge missed opportunity not to put energy efficiency at heart of strategy. *The University of Sussex*.
25. Woodward, K. (2022). Energy Saving Trust responds to UK Government's Energy Security Strategy. *Energy Saving Trust*.
26. Le Page, M. (2022). UK energy security strategy won't provide enough energy or security. *New Scientist*.
27. Dawood, S. (2022). Why the Energy Security Strategy won't control soaring household bills. *New Statesman*.
28. E3G (2022). Energy Security Strategy - E3G response.
29. Thomas, N. *et al.* (2022). UK's new energy security strategy branded 'missed opportunity'. *Financial Times*.
30. Grubb, M. (2022). The UK energy strategy is both cowardly and incoherent. *Financial Times*.
31. Energy Bill 2022.
32. BEIS (2022). Energy Security Bill: factsheets.
33. HM Government (2022). Energy Bill Explanatory Notes.
34. Ang, B. W. *et al.* (2015). Energy security: Definitions, dimensions and indexes. *Renew. Sustain. Energy Rev.*, Vol 42, 1077–1093.
35. International Energy Agency Energy security.
36. Asia Pacific Energy Research Centre (2007). A Quest for Energy Security in the 21st Century: Resources and Constraints. Inst. of Energy Economics, Japan.
37. Cherp, A. *et al.* (2014). The concept of energy security: Beyond the four As. *Energy Policy*, Vol 75, 415–421.
38. Yergin, D. (1988). Energy Security in the 1990s. *Foreign Aff.*, Vol 67, 110–132. Council on Foreign Relations.
39. Deese, D. A. (1979). Energy: Economics, Politics, and Security. *Int. Secur.*, Vol 4, 140–153.
40. Paravantis, J. A. *et al.* (2018). A Geopolitical Review of Definitions, Dimensions and Indicators of Energy Security. in *2018 9th International Conference on Information, Intelligence, Systems and Applications (IISA)*. 1–8.
41. Johansson, B. (2013). A broadened typology on energy and security. *Energy*, Vol 53, 199–205.
42. Hughes, L. (2012). A generic framework for the description and analysis of energy security in an energy system. *Energy Policy*, Vol 42, 221–231.
43. Conway, E. (2022). The surreal, but also real, problem of Britain's gas glut. *Sky News*.
44. Parkhill, K. *et al.* (2013). Transforming the UK Energy System – Public Values, Attitudes and Acceptability. UKERC.
45. BEIS (2021). End to coal power brought forward to October 2024.
46. BEIS (2022). UK to phase out Russian oil imports.
47. Bradshaw, M. (2018). Future UK Gas Security: A Position Paper. UKERC.
48. BEIS (2022). Digest of UK Energy Statistics (DUKES) 2022.
49. BEIS (2020). Digest of UK Energy Statistics 2020.
50. BEIS (2021). Digest of UK Energy Statistics (DUKES) 2021.
51. International Energy Agency (2011). Measuring Short-term Energy Security.
52. Grubb, M. *et al.* (2006). Diversity and security in UK electricity generation: The influence of low-carbon objectives. *Energy Policy*, Vol 34, 4050–4062.
53. International Energy Agency (2021). Security of Clean Energy Transitions.
54. Zakeri, B. *et al.* (2022). Energy Transitions in Europe – Role of Natural Gas in Electricity Prices.
55. Helm, D. (2017). Cost of Energy Review. BEIS.
56. Helm, D. (2021). Luck is not an energy policy – the cost of energy, the price cap and what to do about it.
57. BEIS (2022). Review of Electricity Market Arrangements Consultation Document.
58. Flower, J. *et al.* (2020). Heterogeneity of UK residential heat demand and its impact on the value case for heat pumps. *Energy Policy*, Vol 144, 111593.
59. Smith, O. (2022). Prepay energy customers disconnect over price rises. *BBC News*.
60. Citizens Advice (2022). CA cost of living data dashboard.
61. Intercontinental Exchange Dutch TTF Gas Futures.
62. Reuters (2021). TIMELINE-Nord Stream 2: Russia's legal battle to boost gas supplies to Germany.
63. European Commission (2022). Quarterly report on European gas markets.
64. Graham, E. (2022). Resolving The Energy Price Crisis: Why the UK's future resilience lies in the acceleration of clean energy. E3G.
65. Compass Lexecon (2018). Measures for a sustainable gas storage market.
66. European Commission (2015). The role of gas storage in internal market and in ensuring security of supply.
67. FitzGerald, S. (2020). The effect of Nord Stream 2 on the European gas market. E&C.
68. Gas Infrastructure Europe REMIT Storage Data. *Aggregated Gas Storage Inventory*.
69. Office for National Statistics (2022). Trends in UK imports and exports of fuels.
70. International Gas Union (2022). World LNG Report 2022.
71. Delfs, A. *et al.* (2022). Germany Raises Gas Targets on Concerns Over Russian 'Blackmail'. *Bloomberg.com*.
72. Buckley, R. (2022). The energy crisis affects businesses as well as households. *Cornwall Insight*.
73. BEIS Committee (2022). Energy pricing and the future of the Energy Market.
74. BEIS (2022). Weekly road fuel prices.
75. Department for the Economy (2022). Energy in Northern Ireland 2022.

76. BEIS (2022). Monthly and annual prices of road fuels and petroleum products.
77. Consumer Council Home Heating Oil Price Checker Archive.
78. ENTSO-G (2022). Yearly Supply Outlook 2022/2023.
79. National Grid (2016). Gas Demand Forecasting Methodology.
80. National Grid Gas Transmission (2022). Early engagement on this year's Gas Winter Outlook.
81. Council of the EU (2022). Member states commit to reducing gas demand by 15% next winter.
82. International Energy Agency (2022). Gas Trade Flows.
83. European Parliament (2019). Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC (Text with EEA relevance.).
84. Cambridge Economic Policy Associates (2017). A review of gas security of supply within Great Britain's gas market - From present to 2035.
85. Department of the Environment, Climate and Communications (2021). Gas.
86. BEIS (2022). Energy Trends: UK gas.
87. Trotman, S. (2022). Supply of Liquefied Natural Gas in the UK, 2021. BEIS.
88. Davies, C. (2021). Autumn 2000: when fuel shortages brought UK to virtual standstill. *The Guardian*.
89. The Economist (2021). Why are British petrol stations running dry?
90. National Grid ESO Why do power cuts happen?
91. Ofgem (2022). Final report on the review into the networks' response to Storm Arwen.
92. Rinaldi, S. M. *et al.* (2001). Identifying, understanding, and analyzing critical infrastructure interdependencies. *IEEE Control Syst. Mag.*, Vol 21, 11–25.
93. Ofgem (2020). 9 August 2019 Power Outage Report.
94. MacIver, C. *et al.* (2021). An analysis of the August 9th 2019 GB transmission system frequency incident. *Electr. Power Syst. Res.*, Vol 199, 107444.
95. ITV News (2019). Rail passengers told to claim compensation after major power cut.
96. Freeport LNG (2022). Freeport LNG Provides Update on June 8 incident at its Liquefaction Site.
97. IRSN (2021). Information Sheet: Detection of cracks in pipes of the emergency core cooling system of the reactors No. 1 and No. 2 of the Civaux nuclear power plant.
98. Jaroszweski, D. *et al.* (2021). UK Climate Risk Independent Assessment (CCRA3) Technical Report Chapter 4: Infrastructure.
99. BBC News (2022). London narrowly avoided post-heatwave blackout.
100. Duggan, J. (2022). UK could face blackouts after drought causes European hydropower output to plummet, experts say. i.
101. Quiggin, D. *et al.* (2021). Climate change risk assessment 2021. Chatham House.
102. Reuters (2022). Britain set to hold oil, gas licensing round this year-regulator.
103. Toke, D. *et al.* (2013). The relationship between climate change and energy security: key issues and conclusions. *Environ. Polit.*, Vol 22, 537–552.
104. Fankhauser, S. *et al.* (2022). Delaying clean energy transition would be 'lose-lose' for UK energy security, households and the climate. *University of Oxford*.
105. SEI *et al.* (2021). The Production Gap Report 2021.
106. International Energy Agency (2021). Net Zero by 2050.
107. International Energy Agency (2019). World Energy Investment 2019.
108. Climate Change Committee (2022). Letter: Climate Compatibility of New Oil and Gas Fields.
109. National Grid ESO (2022). Future Energy Scenarios 2022.
110. Climate Change Committee (2020). Sixth Carbon Budget.
111. Climate Change Act 2008.
112. Watson, J. *et al.* (2018). The Security of UK Energy Futures. UKERC.
113. Drax (2018). The great balancing act: what it takes to keep the power grid stable.
114. Nedd, M. *et al.* (2022). Security of Scottish electricity supply - gauging the perceptions of industry stakeholders. Climate Exchange.
115. Cox, E. (2021). The impacts of energy disruptions on society. UKERC.
116. National Grid ESO (2022). Network Options Assessment 2021/22 Refresh.
117. National Grid ESO (2022). The Pathway to 2030 Holistic Network Design.
118. BEIS *et al.* (2022). Electricity networks strategic framework.
119. BEAMA (2022). Growing The Supply Chain For A Net Zero Energy System.
120. Energy & Utility Skills (2018). Skills and Labour Requirements of UK Offshore Wind Industry 2018 to 2032.
121. EngineeringUK (2019). 2019 Excel Resource.
122. Wilson, R. *et al.* (2016). Working Futures 2014 - 2024. UK Commission for Employment and Skills.
123. International Energy Agency (2021). The Role of Critical Minerals in Clean Energy Transitions.
124. BEIS (2022). Resilience for the future: The UK's critical minerals strategy.
125. Dawda, S. *et al.* (2022). Securing a Net-Zero Future: Cyber Risks to the Energy Transition. Royal United Services Institute.
126. Atlantic Council (2022). Securing the Energy Transition Against Cyber Threats.
127. Booz Allen Hamilton (2016). When the lights went out: A comprehensive review of the 2015 attacks on Ukrainian critical infrastructure.
128. BEIS (2021). Statutory Security of Supply Report 2021.
129. BEIS (2013). Energy Market Reform Consultation Annex C: Reliability Standard Methodology.
130. National Grid ESO (2022). Winter Outlook 2022/23: Early view.
131. Scottish Power *et al.* (2022). Better Home, Cooler Planet.
132. Graham, E. *et al.* (2022). Addressing the UK's energy needs at speed. E3G.
133. Rosenow, J. *et al.* (2018). The remaining potential for energy savings in UK households. *Energy Policy*, Vol 121, 542–552.
134. Climate Change Committee (2017). Energy Prices and Bills - impacts of meeting carbon budgets.
135. Department for Levelling Up, Housing and Communities *et al.* (2022). Live tables on Energy Performance of Buildings Certificates.
136. Energy Efficiency Infrastructure Group (2019). The Net Zero Litmus Test: Making energy efficiency a public and private infrastructure investment priority.
137. Phillips, J. *et al.* (2022). Home energy security strategy: the permanent solution for lower bills. E3G.
138. Stavrakas, V. *et al.* (2020). A modular high-resolution demand-side management model to quantify benefits of demand-flexibility in the residential sector. *Energy Convers. Manag.*, Vol 205,
139. Strbac, G. *et al.* (2016). Delivering future-proof energy infrastructure. National Infrastructure Commission.
140. Keay-Bright, S. *et al.* (2021). Project TraDER project summary and lessons learned. Energy Systems Catapult.
141. Ofgem GB Gas Storage Facilities 2021.
142. National Grid Gas Transmission (2022). Gas Winter Review and Consultation.
143. National Grid (2018). Winter Review and Consultation.
144. North Sea Transition Authority (2022). Notification of Application: Gas Storage Licence.

145. Oliver, M. (2022). Rough gas storage site cleared to start filling up within weeks. *The Telegraph*.
146. Gallo, A. B. *et al.* (2016). Energy storage in the energy transition context: A technology review. *Renew. Sustain. Energy Rev.*, Vol 65, 800–822.
147. Cárdenas, B. *et al.* (2021). Energy storage capacity vs. renewable penetration: A study for the UK. *Renew. Energy*, Vol 171, 849–867.
148. Cárdenas, B. *et al.* (2021). Short-, Medium-, and Long-Duration Energy Storage in a 100% Renewable Electricity Grid: A UK Case Study. *Energies*, Vol 14, 8524.
149. MacIver, C. *et al.* (2021). The impact of interconnectors on the GB electricity sector and European carbon emissions. *Energy Policy*, Vol 151, 112170.
150. AbiRafeh, A. *et al.* (2020). The impact of interconnectors on decarbonisation. Aurora Energy Research.
151. Blyth, W. *et al.* (2021). Risk and Investment in Zero-Carbon Electricity Markets. UKERC.
152. Department for Energy & Climate Change (2012). Electricity Market Reform: policy overview.
153. National Grid ESO (2021). National Electricity Transmission System Security and Quality of Supply Standard.
154. Energy Networks Association (2019). Engineering Recommendation P2 Issue 7.
155. Ofgem (2010). RIIO - a new way to regulate energy networks.
156. National Grid ESO (2021). Winter Outlook Report.
157. National Grid Gas Transmission (2021). Gas Winter Outlook 2021/22.
158. BEIS *et al.* (2021). Preparing for and responding to energy emergencies.
159. Department of Energy and Climate Change (2014). Energy Emergencies Executive Committee Annual Report 2014.