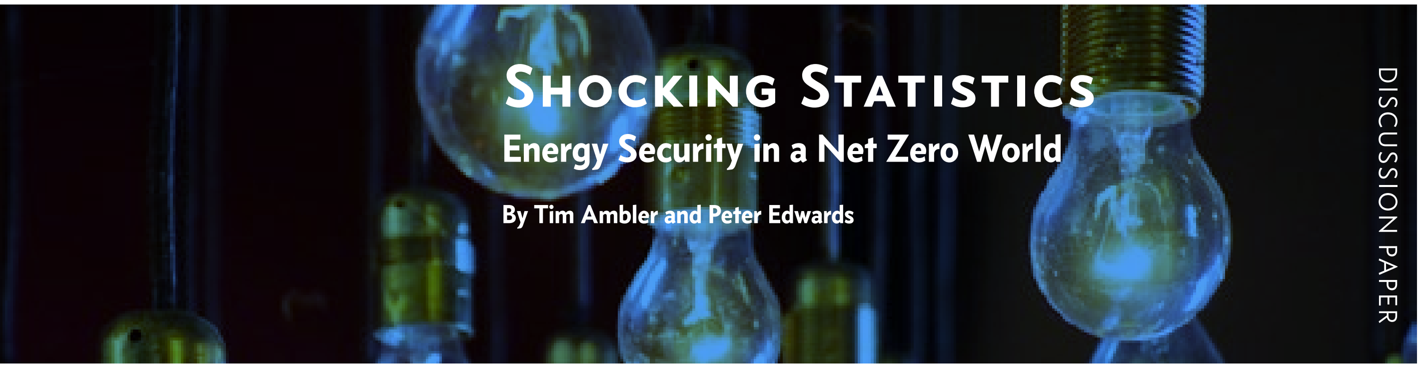

Shocking Statistics

Energy Security in a Net Zero World

By Tim Ambler and Peter Edwards

DISCUSSION PAPER

EXECUTIVE SUMMARY

- Recent disruptions to the global energy market have sharpened focus on what steps are necessary to solidify the UK's future energy security,
- Distribution failure could, in theory, be mitigated by an independent network linking sub-stations with generators but alternative solutions should be urgently examined,
- Net Zero by 2050 necessitates our energy supply coming almost entirely from electricity, but there is currently a lack of clarity on estimated future energy requirements and the appropriate mix of electricity sources,
- Under current plans for the share of UK electricity generated by renewables in 2050, the battery storage investment required is of questionable feasibility,
- Hydrogen is unlikely to be a main fuel for transport or domestic heating. Its higher wastefulness as a storage medium must be considered when modelling electricity requirements and their overall costs,
- Time is running out for planning appropriate investment in baseload, whether in the case of nuclear power or counter-renewables with carbon capture and storage,
- Net carbon zero may require seven times the present electricity generation,
- The Government needs to estimate with high certainty the greatest, least and most likely generational need in order to adequately plan for a secure future energy supply.

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Introduction

A core theme of public and economic policy around the world concerns the transition towards net zero and energy efficiency. Against a backdrop of increasing oil prices, the complicated geostrategic implications of energy trade, and the growing effects of climate change, long-term energy security is the topic on everyone's minds.

As we phase out hydrocarbons (such as butane, ethane, methane, oil, gas, wood, and coal), our energy in a net zero carbon economy will be almost entirely supplied by electricity. The challenge therefore is how much will we need and from where it will be sourced. A move towards renewable sources of energy like solar, wind, hydro (hopefully supported by nuclear power) will leave Britain's energy supply reliant on effective capture, storage, and dissemination by the National Grid.

When we have storms today, some power lines may go down but it is not a national disaster. But what about when we are 100 percent dependent on electricity and the National Grid goes down? Or when almost all of our electricity comes from wind turbines and solar, it is night and the wind does not blow: what do we do then?

This paper on energy security aims to answer these questions, along with addressing concerns about capture and storage of electricity, as well as the increasingly precarious international trade of energy. Since the Government is working on these topics, this paper concludes with a brief review of the Government's current plans as set out in the National Grid's July 2021 "Future Energy Scenarios".[1]

Two Problem Scenarios

Catastrophic distribution failure

There are two kinds of electricity security threats. Under the first scenario there is plenty of electricity but the means of getting it to our factories, homes and hospitals has collapsed (whether through natural or human causes). The second is the reverse: the power connections are fine but electricity generation is inadequate.

The solution to the first problem is simple in theory but probably expensive; we would need to set up multiple fail-safe measures to avoid disruptions in service. Although scale of this project would be immense as we have over 400,000 electricity substations,[2] they could be grouped into areas that could be connected through back-up cabling to the electricity generators. Alongside this, a few more standby generators, probably gas-fired, could be built (or retained), if necessary.

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1 National Grid, 'Future Energy Scenarios 2021', 2021: https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021

2 EMFs.com, 'Final distribution substations': https://www.emfs.info/sources/substations/final/#:~:text=There%20are%20over%20400%2C000%20substations%20in%20the%20UK,exposure%20limits%20-%20see%20more%20detail%20Electric%20fields

Of course, it is not that simple, as substations come in many forms: Step-up Type Substations, Step-down Transformers, Distributions, Underground Distributions, Switchyards, Customer Substations, and System Stations.[3] Given the complexity of such a solution, this would need further costing and evaluation, but the risk of disruption to the distribution of electricity means that a solution to what would otherwise be a national catastrophe needs to be found.

Adequacy of electricity generation

The second problem – lack of energy being generated – is inherently more complex because it comes down to the long-term mix of energy production methods. The working strategy is to rely increasingly on renewables: solar power and sea- and land-based wind turbines, which are expensive to install but cheap to run.

Under the net zero scenario, there will be five sources of electricity: interconnectors (imports), storage, renewables, baseload (such as nuclear and hydro-power) and, *force majeure*, "counter-renewables", namely the traditional carbon emitting generation, with carbon capture and storage (CCS), as needed additionally to meet demand. This paper addresses how BEIS should ensure that these five sources are best balanced to ensure the UK's continuous electricity security.

SOURCES OF ELECTRICITY

Interconnectors

The UK is reliant on interconnectors which are intrinsically insecure because suppliers – i.e. other countries – may not always want to supply us, or may have no available surpluses, or, as we have seen in recent weeks, prices could be excessive. Such international energy sources are also under pressure due to geostrategic factors.

Securing electricity means balancing imports with exports from and to neighbouring countries that are likely to remain compatible with physical infrastructure and geopolitical relations. In 2018, the House of Commons Library reported:

> "After spending most of the previous 25 years as a net exporter of energy the UK became a net importer in 2004. The gap between imports and exports has increased since 2004 and this looks set to continue to increase in the future. This, alongside higher fuel prices and increased concern over the security of energy supply has increased the attention on energy and imports."[4]

The reality is that, even though the Energy White Paper (Figure 3.4) shows net imports at around 1 percent, the UK has no plan to bring net imports under control. In 2019, net imports increased by 25 percent and the following year it decreased by

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3 ELPROCUS, 'What is a Substation', https://www.elprocus.com/what-is-a-substation-definition-types-of-substations/#:~:text=This%20type%20of%20substation%20gets%20the%20power%20supply,by%20using%20a%20transmission%20bus%20to%20transmission%20lines

4 House of Commons Library, 'Energy imports and exports', Oct 2018: https://researchbriefings.files.parliament.uk/documents/SN04046/SN04046.pdf

25 percent[5] but was still 6.3 percent of the market.[6] If there is a single main reason, it is HM Treasury's obdurate refusal, over 20 years, to address nuclear.

Storage

Net zero targets can only be met if renewable energy can be stored cost-effectively.[7] The extent of the need for electricity storage is driven by two factors: whether the usage is considered 'disconnected' or 'connected'. Disconnected usage would involve the use of batteries whereas connected usage taps directly into the power source.

Batteries

Transport will account for the vast majority of the disconnected usage. Batteries look likely to be the future of low-emission road transport (with the possible exception of heavy lorries). Trains are, of course, connected but for road transport batteries seem the way to go, with charging points being commissioned nationwide.

One can discount battery storage as a means of large-scale renewable energy storage to cover national generation shortfalls arising from *Dunkelflaute:* days when the wind does not blow and the sun does not shine. For ten such successive days – surely an entirely reasonable safety net in the United Kingdom – the storage capacity required to cover the shortfall would be 14 TWh at a cost of £4.5 trillion – more than four times the UK public sector spending for 2020/21.[8]

Hydrogen

Hydrogen may seem a workable alternative but it is intrinsically more expensive than directly sourced electricity charging batteries. Plus, the world has already, in effect, voted through increased investment in and use of electric vehicles. Setting up parallel hydrogen refuelling points for hydrogen vehicles alongside the electrical system for battery vehicles would be wasteful as well as dangerous; one spark from the latter would ignite the former.

Hydrogen is unlikely to be a main fuel for transport. Hydrogen, whether blue (from natural gas) or green (from electrolysis), has been widely hyped as a source of electricity, but it is simply an energy carrier; not a source. Its power to volume ratio makes it unsuitable as a fuel for commercial aircraft. The same goes for domestic heating, as converting natural gas distribution to hydrogen and then maintaining it for millions of homes alongside electricity would be very expensive, not to mention the cost of the electricity needed to make hydrogen fuel.

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5 Statista, 'Net electricity imports in the United Kingdom (UK) from 1990 to 2020', Feb 2022: https://www.statista.com/statistics/549158/net-electricity-imports-uk/

6 Gov.uk, 'Digest of UK Energy Statistics 2020', July 2020: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904545/DUKES_2020_Press_Notice_.pdf

7 Physics World, April 2022: https://prod-physicsworld-iop.content.pugpig.com

8 BBC, 'All UK's electricity will come from clean sources by 2035, says PM', Oct 2021: https://www.bbc.co.uk/news/uk-politics-58792261#:~:text=All%20UK's%20electricity%20will%20come%20from%20clean%20sources%20by%202035%2C%20says%20PM,-4%20October%202021&text=-Boris%20Johnson%20has%20said%20all,power%20and%20other%20renewable%20sources./

Converting mass users (such as industry and gas-fired generators) to hydrogen would be another matter. Hydrogen should therefore be considered a form of storage for those two types of users – to be cheaply made only when renewables are in surplus.

Renewables need storage

Storage cannot play a *net* role in providing electricity supply, since its purpose is to use the generation peaks to fill the troughs. Given the volatility of renewables, that becomes more and more crucial as renewables' share of total supply increases. This is far more important than some commentators suggest. For example, Professor Lion Hirth's conclusion that "storage will not be a major part of the solution to this problem within the next 20 to 40 years"[9] is too negative.

Storage needs are dictated primarily by the number of sequential *Dunkelflaute* days. Nothing in this world is certain: Oxford's physics professor Tim Palmer reports that "wind-drought" in 2020 caused North Sea turbines to lose one third of their expected output. Longer term "global stilling" will reduce wind generation for longer periods.[10] Palmer is supported by Oliver Ruhnau and Staffan Qvist (2021) who found that periods with persistently scarce supply usually last no longer than two weeks, but can be as much as nine weeks. Twelve weeks' storage should be allowed for, which would be about three times larger than the scarcest two weeks.[11]

Storage wastage

All forms of electricity storage involve wastage, i.e. one gets back less than one puts in. Naturally enough, some are more wasteful than others. Batteries are the least wasteful with "round-trip efficiencies" between 70 percent and 95 percent, i.e. waste between 30 percent and 5 percent. Hydrogen is probably the most wasteful, with a round-trip efficiency of 47 percent[12] or even less. However, if one allows for the re-use of heat released during the conversion of hydrogen back to electricity in a fuel cell on site, the overall energy efficiency can be increased to 66 percent. All of this needs to be taken into account when modelling electricity requirements and their overall costs.

Renewables

According to Figure 3.4 of the 2020 Energy White Paper, over 70 percent of UK electricity will come from renewables in 2050. Comparison with the data makes this look more than unlikely.

According to Barry Norris, in the calendar year 2021 "there were just 7 days when renewables (predominantly wind but also solar) contributed more than 50 percent

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9 Youtube.com, 'Renewable Power Economics | Lion Hirth', July 2019: https://www.youtube.com/watch?v=caa7HufZiT4

10 Palmer, Tim, 'Gone with the wind', 2022: https://iopscience.iop.org/article/10.1088/2058-7058/35/01/24/pdf

11 Ruhnau, Oliver & Qvist, Staffan, 'Storage requirements in a 100% renewable electricity system: Extreme events and inter-annual variability', 2021: https://www.econstor.eu/handle/10419/236723

12 Science Direct, 'Round Trip Efficiency', 2014: https://www.sciencedirect.com/topics/engineering/round-trip-efficiency of *energy* generation and 16 days when they contributed less than 10 percent" (Emphasis added).[13] This makes sense because the average generated for the year was, according to Norris, 25 percent. To get a mean of 70 percent, the wind must be blowing at the maximum the turbines can tolerate for something like two thirds of the year. If the wind is any stronger, the turbines have to be turned off. That said, Scotland reached 62 percent of electricity via renewables in 2020.[14]

In the electricity supply sector, averages are not very useful. According to Elexon's Balancing Mechanism Reporting System, the average contribution of wind between 1st and 24th March 2022 was 22.8 percent of UK electricity requirements. On March 24th, wind contributed 2.6 percent and on March 19th, 43.8 percent. Industry and consumers are not interested in averages, they need continuous supply.[15]

According to government figures, the actual renewables share of UK *electricity* generation in 2019 was about 23 percent,[16] of which solar contributed about 3 percent (though we don't have an accurate figure due to the unknown amount of household solar installations) and wind contributed 19.8 percent.[17] Whilst the point Norris is making (fluctuations must be taken into account) is valid, his conclusions are distorted by his using energy rather than electricity shares; renewables will always be a smaller proportion of total *energy* (which includes natural gas and petroleum) than total *electricity*.

Baseload

Baseload is the stable electricity generation that continues 24/7, year-round – mostly nuclear and hydro. In practice, these generators can be turned on and off but they are slow to adapt, so they are kept on. Baseload provides useful support for variable energy consumption and generation; as winter months need more electricity than summer, one would expect baseload to be reduced during the summer. Against that, summer days are sunnier but less windy so generate different mixes of electricity.

Optimising baseload is a tricky business. In 2020, nuclear power contributed 16.1 percent and hydro 2.2 percent of our electricity needs.[18] This has declined steadily, and will continue to do so, as all current nuclear plants will be closed by 2035. At that point, only Hinkley Point C will be operating with, possibly, Sizewell C and Wylfa (which will be of equivalent size) to follow. Sizewell C is expected to meet

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13 Physics World, April 2022: https://prod-physicsworld-iop.content.pugpig.com

14 Gov.uk, 'Electricity generation and supply in Scotland, Wales, Northern Ireland and England, 2016 to 2020', Dec 2021: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1043323/Regional_Electricity_Generation_and_Supply_2016-2020.pdf

15 BMRS, 'Generation by Fuel Type': https://www.bmreports.com/bmrs/?q=generation/fueltype/current

16 Gov.uk, 'UK Energy In Brief', 2021: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1032260/UK_Energy_in_Brief_2021.pdf

17 Gov.uk, 'Wind powered electricity in the UK', 2019: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/875384/Wind_powered_electricity_in_the_UK.pdf

18 Gov.uk, 'UK Energy In Brief', 2021: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1032260/UK_Energy_in_Brief_2021.pdf seven percent of UK electricity usage[19] so the three together would provide about 20 percent.

Ideally, baseload should be set high enough to ensure that baseload and renewables produce enough surpluses to go into storage to offset the deficits during *Dunkelflaute* days, after allowing for round-trip efficiencies.

Modelling the optimal baseload share is beyond our scope here. However, in our previous paper,[20] we estimated that in a Net Zero world, total electricity needs would be about seven times the current usage and baseload would need to be about 40 percent of that, i.e. that it would need to be more than *thirteen times*[21] the current level. Given HM Treasury's reluctance to build nuclear, plus the lead time for approving and building the nuclear plants they do approve, and the absence of a value for money funding concept, this seems somewhat unlikely.[22]

It is worth looking at new methods of funding nuclear power plants. They are incredibly expensive and time-consuming to build, and often they are a bad deal for consumers. Currently, with the Contract for Difference (CFD) model, the Treasury agrees a "strike price" – the rate at which they're willing to pay for energy once production starts. Based on the trajectory of energy prices, the government could then end up saving money or paying over the odds. As it turns out, in 2017, the National Audit Office estimated the excess (over market) cost to consumers of Hinkley Point C due to the 'strike price' will be £50 billion.[23] The Treasury's Regulated Asset Base (RAB) model has raised some concerns; it's possible that it would "add money to consumer bills over the lifetime of the project, but it also leaves consumers vulnerable to cost overruns, which have plagued previous nuclear developments".[24] Those however relate to the old school large scale plants such as Hinkley Point C, whereas the smaller modern reactors would be quicker to build and easier to finance probably by their customers, i.e. the electricity distributors.

Counter-renewables

To the extent that baseload falls short, gas-fired generation will be required. That does at least have two advantages: the technology is well known and generators can be speedily turned on and off to match changes in the weather, though with the added complication of CCS. The only change needed to the arithmetic above is that the counter-renewables contribution must be added to the baseload.

19 Glenigan, 'Hinkley Point C: Powering our future?': https://www.glenigan.com/hinkley-point-c-powering-our-future/#:~:text=Fact%20%E2%80%93%20The%20power%20station%20will%20operate%20for,25%2C000%20employment%20opportunities%20throughout%20its%2010-year%20build%20programme.

20 Ambler, Tim; Edwards, Peter & Kelly, Michael, 'Blind Man's Buff? The UK Net Zero Strategy', Nov 2021: https://www.adamsmith.org/research/blind-mans-buff-the-uk-net-zero-strategy

21 2019: 20 percent of 300TWh = 60. 40 percent of 2,000 TWh = 800. 800/60 = 13.3

22 Malnick, Edward, 'Boris Johnson frustrated with Rishi Sunak over 'resistance' to new nuclear power plants', Telegraph, March 2022: https://www.telegraph.co.uk/politics/2022/03/19/boris-johnson-frustrated-rishi-sunak-resistance-new-nuclear/

23 Ambrose, Jillian Hinkley Points Cost to Consumers Surges to £50bn, Telegraph, July 2017: https://www.telegraph.co.uk/business/2017/07/18/hinkley-points-cost-consumers-surges-50bn/

24 BBC, 'New funding plan paves way for Sizewell C nuclear plant', Oct 2021: https://www.bbc.co.uk/news/business-59051025

But decisions need to be made soon. As noted above, lead times are long: on 8th March 2022, Dr Doug Parr (Chief Scientist at Greenpeace UK) told the BEIS Select Committee: "If you look at the average length of time between a licence being granted and fossil fuels flowing in the North Sea, it is 28 years, which takes us to 2050." If we want substantial gas generation to continue, as the above figures indicate is almost certain, we need to see the plans now.

FACING THE FUTURE

The National Grid envisages four alternative strategies, the first three taking the UK to a net zero carbon 2050 and the fourth reducing emissions to 73 percent of 1990 levels:[25]

- CONSUMER TRANSFORMATION (changing the way we use energy): Electrified heating, consumers willing to change behaviour, high energy efficiency and demand side flexibility.
- SYSTEM TRANSFORMATION (changing generation and supply): Hydrogen for heating, consumers less inclined to change behaviour, lower energy efficiency and supply side flexibility.
- LEADING THE WAY (best of both the first two): Fastest credible decarbonisation, significant lifestyle change, mixture of hydrogen and electrification for heating.
- STEADY PROGRESSION: Slowest credible decarbonisation, minimal behaviour change and decarbonisation in power and transport but not heat.

It is far from clear how these scenarios enable the Grid to determine the amount of energy electricity, natural gas, hydrogen and biomass will contribute to each one. The Grid estimates the total energy requirement for each of the four will be 1,136, 1,792, 1,202 and 1,406 TWh respectively but the calculations for these estimates, and their rationales, are not given. We are asked to believe that changing consumer behaviour, though that is no easy matter, will reduce energy consumption by about 30 percent. The hydrogen figures do not seem to include the electricity needed to make hydrogen fuel itself, nor the low round-trip efficiencies. In short, it is hard to give any credibility to this approach to estimating total electricity demand in a zero carbon UK, nor to the estimates for each type of energy.

These make for interesting comparisons with the BEIS 'scenarios'. The Minister's reply on 28th March to a parliamentary question tabled by Craig Mackinlay MP was: "Annex O of the Government's Energy and Emission Projections provides four indicative scenarios. These have two levels of demand (higher and lower) and show capacity mixes that could meet this demand, while ensuring emissions fall in line with legislated ambition and costs to consumers are minimised." That explains 'scenarios' as follows: "The scenarios are indicative of what a future energy gen-

25 National Grid, 'Future Energy Scenarios in five minutes', July 2021: https://www.nationalgrideso.com/document/199926/download eration mix may look like rather than prescriptive forecasts." The Net Zero higher and lower electricity scenarios are 765 TWh and 575 TWh.

A more realistic forecast has been previously estimated in the region of 2,000 TWh[26] but it is clear from the variety of figures above that much uncertainty remains.

CONCLUSIONS

This paper addresses two major national security concerns. First, do we have adequate electricity *distribution* back-up if the national network goes down whether due to a natural or man-made catastrophe? Second, will we have enough *generational and storage* capacity when we get to zero carbon?

- For the first concern, an independent network linking sub-stations with generators might be the solution but alternatives should be evaluated;
- Net Zero carbon may require seven times the present electricity generation. BEIS needs to estimate with high certainty the greatest, least and most likely generational need because, without knowing those values, how can it plan adequate electricity supply?
- There will be five sources of electricity supply: interconnectors (imports), storage, renewables, baseload and counter-renewables (gas-fired generation with CCS);
- Interconnectors and storage should have minimal overall contribution to usage. Their role is to shift supply from strong wind and sun conditions (i.e. renewables are providing surpluses) to deficit conditions (*Dunkelflaute* days). Storage is intrinsically wasteful and the relevant round-trip efficiencies should be factored into any modelling of total electricity needs;
- Renewables should provide most of our electricity needs but will need to be increased by 13 times if the 2,000 TWh forecast for 2050 is correct. Is that feasible?
- Similarly, 40 percent baseload, to balance 60 percent renewables, will also require from nuclear and hydro a 13-fold increase. Is that feasible?
- If BEIS is to stand any chance of providing the electricity the UK will need in a Net Zero carbon 2050 scenario, bearing in mind the long lead times for generating plants, they need a professional forecast of our need, and soon.

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26 Ambler, Tim; Edwards, Peter & Kelly, Michael, 'Blind Man's Buff? The UK Net Zero Strategy', Nov 2021: https://www.adamsmith.org/research/blind-mans-buff-the-uk-net-zero-strategy