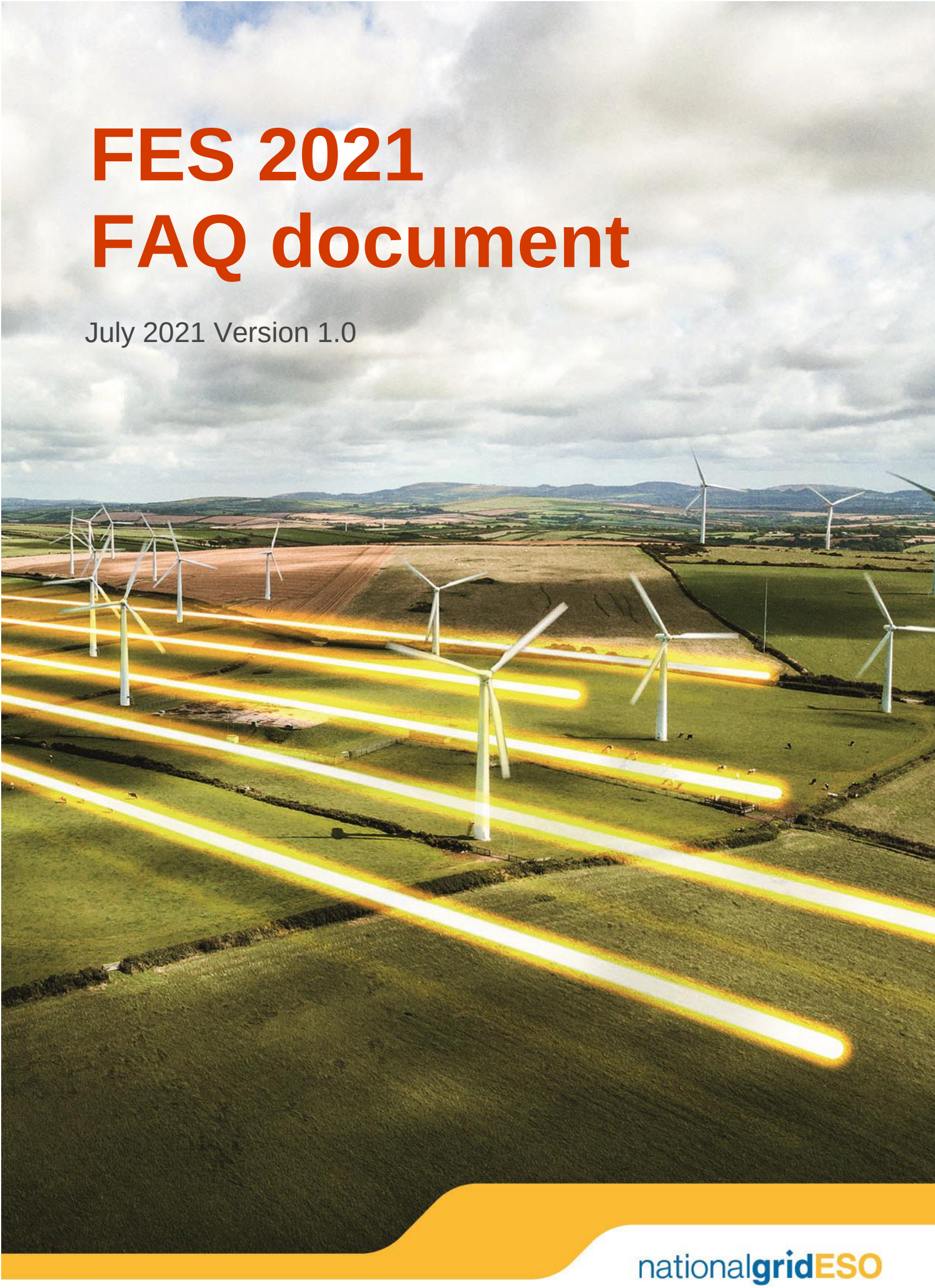
FES 2021
FAQ document

July 2021 Version 1.0



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Introduction

Thank you for your interest in the FES 2021 FAQ document.

This is just one publication in the suite of documents that make up FES 2021 together with the main report, FES in 5, Modelling Methods and the Scenario Framework. The Data Workbook contains all the outputs from the numerous models: the detailed tables, graphs and charts.

For more information and to view each of these documents visit our website.

This FAQ document seeks to answer the main questions we received during the week of the FES 2021. launch.

Any further queries received during August will be added to this document and highlighted.

If you have any queries, please contact FES@nationalgrideso.com

Many thanks

FES team

Net zero

1. **Are there any better ways to capture the energy from home DERs rather than taking payments through SEG by exporting to grid?**

FES relies on home DERs to varying extents across the scenarios – broadly in line with the "level of societal change" axis. It is assumed that any electricity not used locally is sold back to the grid (e.g. via SEG) but we appreciate that with the growth of peer to peer trading, Blockchain etc, it may be possible for locally produced electricity to be consumed more locally as well. This could be directly or via local storage. This is an area that we are keen to expand our knowledge in given the potential for increased focus in later FES results.

2. **Can we see a breakdown of carbon emissions forecasting for each of the sectors?**

These are available in NZ.5 of the data workbook and shown on page 37 of the main FES 2021 interactive document.

3. **Do you model UK GHG emissions in 2030 and 2050 on a consumption basis in the four scenarios? If so, what are they?**

Annual UK GHG emissions from 2020 to 2050 are provided in NZ.5 of the data workbook and page 37 of the main FES document. These are modelled in accordance with IPCC accounting and so do not include emissions outside of the UK, but which are related to UK consumption.

4. **Do you publish your methodology for calculating carbon emissions in your published figures and your data sources?**

The FES Modelling Methods 2021 document, which can be found in the FES 2021 document section of the FES website, details the modelling methods used in FES. This includes how emissions are incorporated into our modelling.

5. **Do you think that the UK are moving faster than other countries to decarbonise? Will this put us at a disadvantage?**

The UK was the first was the first major economy to put a net zero commitment into law. However, moving quickly shouldn't put us at a disadvantage. Instead the UK should be well placed to develop new and innovative low carbon industries and technologies, which will create jobs and be exported around the world.

6. **How can LEPs work with you and other stakeholders to deliver net zero across their areas?**

We are keen to engage with LEPs (Local Enterprise Partnerships) and to share data from our modelling. As part of our regional FES work, and in addition to more granular remodelling, we will be ramping up our engagement with stakeholders on a local as well as a GB-level basis.

7. **Emissions will increase this year. What will make them decrease next year?**

We do expect to see an uptick in emissions as society continues to reopen and due to expected economic recovery. Moving forward in future years the decarbonisation effort across many sectors, including power, heat and transport, will continue to reduce emissions. Annual emissions by sector are given in NZ.5 in the data workbook and page 37 of the main FES document.

8. **How are we dealing with embodied carbon, or problems related to lithium mining and discarding the EV batteries etc?**

FES analysis does not consider embodied carbon. We note that, as a technology, EVs do have a higher embodied carbon from production. However, their lifecycle emissions are much lower due to lack of tailpipe emissions (based on many studies).

9. **How are you ensuring the carbon emissions from interconnectors? This is highly dependent on new interconnectors as well as what other EU countries are doing.**

Current international carbon accounting rules account for emissions in the country they are produced. We follow these rules and so emissions relating to interconnector imports and exports are not included in the analysis (i.e. we model interconnector flows as zero emissions).

10. **How are you predicting the carbon intensity factors for each fuel type every year? For example, biomass is at 120 now, what about in 2050?**

We utilise a dispatch model to calculate the outputs of each type of plant, and its associated carbon output per year (based on assumed carbon intensity of generation). Page 23 of the FES Modelling Methods 2021 document, which can be found in the FES 2021 document section of the FES website, provides more detail on how carbon intensity is calculated.

11. **How are you validating the prediction of each of the scenarios? At the end of the day these are all based on big assumptions.**

There is too much uncertainty in the future for a credible single view of the future in the timeframe which FES considers (out to 2050), making validation of individual technologies difficult. Instead we use a combination of in-depth analysis by our team of experienced analysts and stakeholder feedback to develop scenarios which represent the "credible range of uncertainty" that the 2050 energy system could fit into.

12. **Is there an impact on UK net zero targets if decarbonisation targets are missed globally? What is your view on pathways to Net zero compared to EU for example?**

While the focus of FES is on UK emissions to limit global temperature rises, net zero by 2050 must be adopted as a global target. Some aspects of UK decarbonisation will be impacted by global issues (e.g. in relation to supply chains etc) but, equally, there are other elements (e.g. consumer behaviour changes) that are more independent. We note in the FES report (p27) that net zero commitments now cover over half the world's GDP, including the EU.

13. **Is there any benefit in splitting the FES into the devolved governments? Differences in planning policy and targets will surely make significant variations?**

In FES 2021, based on stakeholder feedback, we have begun to take a more regional approach, for example with the development of our regional heat model. This regional approach is an area we are putting greater resource into for the future and we hope to be able to provide more a greater geographical granularity of results in future work (e.g. at developed government level).

14. **Is there any data outlining year on year negative emissions or contribution from BECCS?**

Negative emissions by type, including BECCS, can be found on NZ.6 of the Data Workbook. This is also explored on page 38 of the main FES 2021 interactive document.

15. **Is there any interest in community battery setups for energy storage to support the high demand from EVs?**

Our analysis includes decentralised battery storage (Table ES1 of the Data Workbook) although we don't specify if this is "community" storage or "local network" storage. At a high level, the amount of decentralised storage increases along the level of societal change axis of the Scenario Framework.

16. **Offshore wind is key to all scenarios. Complexity & time in reg. process & links to grid make this challenging what assumptions on improvements are made?**

Our analysis considers offshore wind to be the dominant generation technology between now and 2050 - supported by government targets and a lower levelised cost of energy (LCoE) compared to

other forms of low-carbon electricity generation. As ESO we are working closely with industry on how to improve offshore connections - including via our Offshore Coordination work (https://www.nationalgrideso.com/future-energy/projects/offshore-coordination-project).

17. What assumptions have changed for net zero projections compared to last year?

Assumptions for non-energy sectors are taken from the CCC and given on page 34 of the main FES 2021 interactive document. More generally changes from FES 2020 are detailed in the Key Changes document available here (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents).

18. What happens after 2050, are we continuing to go down the negative emission routes?

Leading the Way delivers net negative emissions by 2047, while CT and ST reach net zero in 2050. While we don't explicitly model beyond 2050 now, we would expect negative emissions to continue and residual emissions to continue reducing. Some international climate change modelling suggests an overshoot of negative emissions may be needed beyond net zero to stabilise and/or reduce global temperature rise.

19. What's more important to meeting net zero? hydrogen or BECCS?

Our analysis shows that both BECCS and hydrogen will be important to meeting net zero and, indeed, that it will be difficult to meet net zero without them. They often play different roles within the energy system and so are not necessarily in direct competition.

20. When looking at nature-based solutions and BECCS are we accounting for the removal of carbon sinks, carbon leakage and harmful logging practices?

Yes, these are built into our assumptions around land use change and forestry – we follow standard carbon accounting assumptions on these and engage regularly with the CCC.

21. When you talk about uncertainties, how do you view uncertainties around hydrogen/CCUS performance and availability?

There are uncertainties around both hydrogen and CCUS in the future. To reflect these uncertainties, the role and capacity of each technologies is flexed across all these scenarios. For example, across scenarios in 2050 hydrogen supply varies between 52 TWh and 475 TWh, and gas with CCS power generation capacity ranges from 0 to 21.5 GW.

22. **Which industries/stakeholders are most likely to pushback on your projections?**

We engage with a wide range of stakeholders across all sectors which contribute to FES. Detail on the stakeholder feedback for the next round of FES, which often includes comments on the previous iteration, is published each year in spring. As you would expect, there is a wide range of opinion on the future of energy and our assumptions in FES and this document seeks to demonstrate this. Last year's document can be viewed here - https://www.nationalgrideso.com/document/187746/download.

23. Why have the cost of implementing two infrastructures - one for electric vehicles and one for H2? Why not cars, trucks, ships, etc all H2?

Different technologies have different advantages and disadvantages whilst different transport sectors have different needs, for example different travel ranges and weights to carry. Based on stakeholder feedback this leads to a range of vectors being used for transport sectors. In general, hydrogen is a better solution for larger vehicles where electrification is less suitable (e.g. articulated HGVs, shipping etc).

24. Why is the building sector not included as a key sector (at least in the UK) needing to make changes?

The building sector is a key element of our modelling although it is not explicitly listed in our analysis. Instead, input from the building sector contributes to important modelling factors like the quality of building stock and household thermal efficiency.

25. **Wouldn't a "most likely pathway"-type scenario be most useful for planning the energy system? If so, why isn't there one?**

There is too much uncertainty in the future for a credible single view of the future in the timeframe which FES considers (i.e. all the way out to 2050). Scenarios are a powerful tool for understanding uncertainty and developing strategy accordingly. By providing a range of credible futures, we can be confident that the reality will be captured somewhere within that range. However, we do provide a 5-year forecast; including by technology type which can be found in the Data Workbook.

26. **How much domestic energy efficiency for heating (thermal efficiency) do you have in CT and LW, please?**

When building fabric changes and consumer behaviour change are both included, Leading the Way has the highest level of total saving in underlying heat demand in 2050 (86 TWh) followed by Consumer Transformation (73 TWh). More detail is provided in CV.13 in the Data Workbook and on p51 of the main FES 2021 interactive document.

27. **How will 2 TWh of hydrogen be produced, stored and distributed through our existing gas grid plumbing. Who is working on the detail?**

The 2 TWh referenced in our 4th Key Message is the lower end of the range and more is needed in other net zero scenarios. Hydrogen production varies across the scenarios (e.g. electrolysis and methane reforming with CCUS) as does the role of the existing natural gas system to transport the hydrogen. However, we are assuming that large-scale hydrogen storage will be in the form of salt caverns whereas smaller scale could utilise high-pressure tanks. As set out in the Key Messages, we believe this is an important area requiring focus to meet net zero and roles and responsibilities will be part of this.

28. **Hydrogen storage has a very different profile across the scenarios - do you have any views on what kinds of storage would be needed to meet this in each case?**

FL.6 in the Data Workbook and pages 105 and 141 of the main FES 2021 interactive document show the required hydrogen storage capacity per scenario from 2020-2050 in five-year increments. FL.7 in the data workbook and page 142 of the main FES document shows the monthly stock level of hydrogen storage in 2050 for each scenario. We are assuming that large-scale hydrogen storage will be in the form of salt caverns whereas smaller scale could utilise high-pressure tanks.

29. **In the FES data workbook, worksheet BB1, there seems to be differences in the 2020 starting point between the four scenarios. What is the reasoning behind this?**

There are two reasons for this. One of the line items "Srg_BB001" Battery Capacity, contained an error which has been corrected in V2 of the data workbook. Other items in the building blocks have some differences in the baseline year as a result of data not being fully available for this year at the time the analysis was carried out, meaning that the baseline year is partially modelled for some areas which has given rise to these variances.

Transport demand

1. **Have you considered the availability of lithium and other key materials for EVs and stationary battery storage?**

Yes, this is considered in our modelling although we don't specify battery technologies or chemistries...We don't foresee global shortages of lithium based on current information. It is interesting to note that there are now projects being considered to mine lithium in the UK.

2. **Are you confident EV manufacturers support the move to V2G for demand side response to meet the scenario Leading the Way?**

Historically there has been some divergence in views on V2G from manufacturers with some very supportive and some less sure (e.g. due to concerns around battery cycling). As ESO we work very closely with EV manufacturers as we see V2G as an important service that will help with system balancing in the future.

3. **Can you tell us about your expectations of miles travelled over the period by different types of vehicles? Do you see any significant reduction in mobility?**

The number of miles travelled varies not only by vehicle but also by scenario. For instance, LW sees fewer cars in total as trends like ride-sharing increase (but these vehicles do a greater number of miles). More information can be found in Table ED5 of the Data Workbook and in the Modelling Methods document (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents).

4. **You refer to winter peak charging but by 2050 won't we want to move demand away from periods of low wind rather than the traditional peak?**

The ability of EVs to respond to price or other signals will apply to peak demand periods initially but, as more and more renewables connect to the system, it will become increasingly important for these signals to incentivise EV demand to move to periods when renewable output is high rather than low. We discuss in the document the changing nature of peak demand. For instance, when wind generation is high at the traditional winter peak, this will be less of an issue, but we still expect it to be a challenging time on the system. However, shifting demand away from low renewable periods and into high renewable periods will become increasingly important irrespective of demand.

5. **Why do you not factor the availability of key materials - notably lithium - into your planning or options?**

We do not model specific battery chemistries in our analysis, but we are not currently aware of a shortage of lithium. In addition, we are aware of potential options other than lithium for use in EVs and battery storage more generally.

6. **What are your assumptions regarding the costs of V2G hardware?**

We recognise that bi-directional chargers are more expensive than uni-directional chargers now but consider that the marginal cost difference will reduce over time. This assumption supports our uptake numbers for V2G

7. **How do you see EVs contributing to the evening peak when cars will potentially have their lowest levels of charge then (returning home from work)?**

We expect battery capacities to increase over time, along with corresponding vehicle ranges. In addition, average daily travel distances are likely to be relatively low compared to expected ranges, so many vehicles will have plenty of spare capacity available when they return home. However, even when this is not the case, smart charging will allow those vehicles that require charging to do so at the most appropriate time (which may be away from the evening peak or to a time of high renewable output/low price).

8. **Is there an impact of increasing price of electricity and smart charging uptake? What incentives/situations would drive consumers to go for smart charging?**

We see the step to owning an EV being the trigger to move to time of use tariffs due to the savings in the cost of electricity at times of high renewable output. This is important as we consider EVs to be an important way of integrating renewables into the electricity system.

9. **Do you see V2G only as a way to reduce peak demand, or can it work to shift demand over longer periods (i.e. days) to cover periods of low wind generation?**

We consider V2G to have the ability to do more than just reduce peak demand as, unlike smart charging of EVs, it has the ability to return power to the grid. However, it is important to bear in mind that the primary purpose of EVs is transportation and so use for longer term storage would mean that the vehicle is not driven for the period in question which may not be a realistic assumption except in certain situations (e.g. if the EV is at a long-stay car park).

10. **When we talk about achieving cost parity for low-emissions private vehicles do we mean for the consumer or to the system/government. Specifically, fuel duty...**

Our road transport modelling is underpinned by the "Total Cost of Ownership" of different types of vehicle and this cost is the cost to the consumer (albeit with existing subsidies reflected). We acknowledge that transitioning to EVs will impact the treasury (i.e. as receipts from fuel duty reduce) but assume that this reduction is offset separately (i.e. in a way that does not deter decarbonisation of transport).

11. **What are your assumptions on Electrification of Rail?**

The way that rail is decarbonised varies slightly across the scenarios but, where appropriate relies on direct electrification. Where this is not possible, we assume use of batteries as well as some hydrogen (e.g. hybrid systems) where required.
This is in line with the government policy target to remove diesel trains by 2040.

12. **Previously UK bought 2 million new cars every year, and 7 million used cars on trickle-down. This will not work for poorer motorists.**

We are already seeing a second-hand market for EVs and expect this to grow between now and 2030. However, affordability and consumer protection are very important as set out in our 2nd FES 2021 Key Message.

13. **Do any of your scenarios include great use of public transport to reduce car ownership and miles travelled?**

Yes - this increase in the scenarios alongside the “level of societal change” axis and is part of the reason for Leading the Way to have fewer vehicles on the road by 2050 than the other scenarios (although some of these vehicles do a greater number of miles).

14. **The DSOs up to now don’t seem too concerned about EV loading their systems. Is this starting to change as FES scenarios predicts faster adoption?**

We can’t speak directly for the DSOs, but it is fair to say that smart charging is as important at a local level as it is at ESO level (i.e. for local as well as wider system balancing).

15. **When a wind lull prevails, why would an EV owner who is a V2G subscriber return charge from their battery to the grid? Will the financial incentive be enough?**

Consumers will be able to override V2G or smart response to charge when they want, but innovation trials have shown that as consumers become more comfortable with this technology this activity happens less and less over time as they realise that the automatic background operation still provides them with a charged vehicle when they need it. More generally, we expect that there will be stronger market incentives for this behaviour in the future than there are now as the generation mix contains more and more renewable capacity.

16. **How have your AV assumptions changed from FES20?**

There has been minimal change to our assumptions in relation to autonomous vehicles (AV) compared to FES 2020. In general, AV allows greater sharing of vehicles, especially in Leading the Way, and while an individual car may travel more miles there are fewer cars.

17. What incentives are assumed to motivate smart charging to help achieve the 60% peak shaving?

We think that the main incentive will be the ability to reduce the costs of charging via time of use tariffs (i.e. drivers incentivised to charge their vehicles when the price is low and renewable output is highest). However, there may also be opportunities for EV users to provide grid services at a local and GB level directly to system operators or via aggregators.

18. Will electrification infrastructure and vehicle advancement / innovation for HGV's outpace H2 infrastructure deployment, e.g. H2 car been overtaken by EV?

We have some hydrogen cars in our System Transformation scenario where there is the most hydrogen infrastructure. However, we mostly assume dominance of EVs based on current uptake rates and the speed of development of range and variety of vehicles.

19. Have you made projections for the uptake rate of EV charging infrastructure, such as the total network facing capacity of chargers?

In our modelling we tend to focus on the number of EVs rather than the number chargers. While the number of EVs may be used as a high-level proxy it is possible for there to be more chargers than EVs (e.g. it is important to consider different types of charger such as residential, destination, forecourt etc).

20. With the world moving towards hybrid working, are we expecting a change in charging patterns and reduction in demand?

Yes, this is something that we are monitoring closely. However, the changes that could result from the restrictions around COVID-19 align with our “level of societal change” axis and so are included to an extent.

21. How can you forecast anything about charging and V2G when you don't know how many people can charge from home?

We assume how many EV owners can charge at home based on data round how many houses have off-road parking. This is also a parameter that varies across the scenarios (i.e. we assume more home charging as we move up the "level of societal change" axis of the Scenario Framework).

22. Are we assuming that all EVs come with V2G? if so, when will this happen?

V2G (vehicle-to-grid) is more to do with the charger than the EV itself. We certainly expect that the ability to participate in V2G will increase in the system and that the costs of bi-directional chargers will decrease accordingly. It may also be possible for bi-directional charging ability to be built into the vehicles themselves and we would be keen to receive any views on this from stakeholders.

23. When is motor way charging going to catch up to the increase in EVs? Are the govt policies anywhere close for this to happen?

The government recently published its Transport Decarbonisation Plan (https://www.gov.uk/government/publications/transport-decarbonisation-plan) which includes commitments to have:

- at least 6 high powered, open access charge points (150–350 kilowatt capable) at motorway service areas in England, with some larger sites having as many as 10–12, by 2023; and
- around 6,000 high powered charge points across England’s motorways and major A roads by 2035.

24. Are we expecting increase in EVs, taxis, Uber and a reduction in car ownership?

This varies by scenario but Leading the Way, our scenario which assumes the highest level of societal change, has significantly fewer vehicles on the road than the other scenarios for this reason.

25. Could COVID reduce use of public transport if it remains in the community long term?
We expect any impact of COVID-19 on use of public transport to be more short term than long term.

Heat in buildings (demand)

1. **Have you considered the potential physical constraints with the transition to heat pumps such as space for external vents, or internal space for water tanks?**

Yes, this is covered in our analysis. Our new spatial heat model includes building stock data as an input to mitigate the risk of heating technologies being applied to buildings that cannot support them. This includes space for hot water tanks for thermal storage etc.

2. **Can you give me a range of number of boiler installations required per year and the reasons for those projections?**

The number homes being heated by natural gas boilers in each year varies by scenario and can be found in tab CV.b of the Data Workbook. Residential hydrogen boiler installations can be found in figure CV.15 (p51 of the main FES 2021 interactive document). The projections are based on the results of our new spatial heat model. More information can be found in the Modelling Methods document but, at a high level, this model considers individual building characteristics and seeks the most cost-effective solution to decarbonise residential and commercial heating within the confine of the high-level scenario assumptions (e.g. more electrification in CT, more hydrogen in ST and faster decarbonisation in LW than SP).

3. **Do we need so many heat pumps? Can we not retro fit existing boilers for hydrogen? Looks like there is more drive for that too from DNO.**

We explore the credible range of uncertainty of low carbon heating technologies in FES. Our Consumer Transformation scenario has more heat pumps than System Transformation which has more of a focus on hydrogen. It's important to emphasise that the future won't be entirely heat pump or hydrogen boiler lead - but will be a mixture of different technologies to suit the needs of the specific housing type. Before retrofitting low carbon heating technologies in existing homes, there will be several factors that need to be considered - including cost, consumer choice and location to infrastructure such as to a hydrogen network.

4. **Do you have a breakdown of which technologies are paired with thermal storage, and in what type of housing these may be located?**

At a high-level thermal storage tends to be paired with heat pumps in our analysis. In terms of what type of housing these are located in, the new spatial heat model considers individual building characteristics when considering whether heat pumps are suitable. We do not publish this level of detail but would be willing to discuss further if this would be useful (email Box.FES@nationalgrideso.com).

5. **Do you have lots of hot water tanks in your scenarios?**

Yes, hot water tanks are considered in our scenarios as a form of thermal storage - particularly alongside heat pumps. Where these are not assumed to be available (e.g. due to space considerations), other thermal storage solutions are assumed such as phase change materials.

6. **Do you think higher electricity prices vs gas will inhibit electrification of heat?**

There is a risk that this may happen but, equally, this is an example of how important time of use tariffs will be for the electrification of heat as well as how incentives may be beneficial to stimulate uptake. Also, the comparison between the cost of natural gas and electricity is in some ways less relevant to the comparison of electricity vs hydrogen in the future as we seek to decarbonise heating.

7. **Does the emissions modelling include the embedded carbon from infrastructure/fabric upgrades?**

No, the emissions modelling doesn't include embedded carbon from infrastructure or fabric upgrades at an individual level. However, at a high level this is included in emissions from the Industrial and Commercial (I&C) sector.

8. **Does the model incorporate the expected reduction in heat pump efficiency associated with the phase out of HCFC refrigerants?**

We have not incorporated this type of detail into our spatial heat modelling this year as there is already a need for assumptions around the precise estimates for heat pump efficiency even before considering the type of refrigerant. We await evidence from trials and stakeholder feedback to potentially explore this topic further and welcome any information that can be provided.

9. **Does today's heating demand include that from electrical pumps on boilers?**

Yes, this electricity demand is implicitly included in our baseline levels (which are based on metering) although we are not able to break it out at a component level.

10. **Have you accounted for additional heating load due to storage inefficiencies, and additional demand required to transfer heat to & from storage?**

Yes, this type of energy loss is reflected in the efficiency assumptions applied to thermal storage in our analysis as it's important to ensure that there is sufficient energy supply to meet demand.

11. **How do annual consumption savings from insulation and behaviour change translate to peak demand savings?**

In addition to reducing the annual heating demand of a building, thermal insultation is also assumed to support the ability for heating to be reduced for periods of around 3-4 hours (e.g. over the evening peak). Similarly, being about to assume a lower temperature on the thermostat at peak means that less input energy is required to heat the building. The new spatial heat model can optimise this type of effect in conjunction with use of hybrid systems and thermal storage at peak times.

12. **How do Local Authority challenges and ambitions align with your regional heat analysis?**

This is the first year that we have been able to include local information in our residential and commercial heat modelling. At present we have not applied local policies and ambitions into the modelling, but this is an area we intend to focus on for the next FES publication as part of our regionalisation work.

13. **How do you implement the operational switch between gas and hydrogen boilers/networks?**

We assume that the transition from natural gas to hydrogen is based around industrial clusters acting as an anchor for hydrogen supply within a region. These hubs could then be connected by a "hydrogen backbone" which would supply and store hydrogen - with hydrogen supply to the wider region growing out from these hubs. More information is available on p105 of the main FES 2021 interactive document.

14. **How many houses are assumed to shift demand at peak and for how long?**

Pages 145 to 147 of the main FES 2021 interactive document set out our assumptions in relation to shifting heat demand at peak times. This flexibility covers several different heat solutions (e.g. thermal storage, hybrid systems etc) and most of the information is in energy terms rather than number of houses. We assume a shifting of demand for 3-4 hours.

15. **I noticed there are far more Ground Source Heat Pumps in this year's analysis. Are these instead of ASHPs compared to previous years' scenarios? And why?**

Yes, we have revised the proportion of Ground Source Heat pumps (GSHPs) in FES 2021, due to extensive stakeholder feedback during our most recent engagement cycle. Feedback suggested that GSHPs can be applicable to a wider range of properties than previously considered - for instance due to the potential for individual units to share a ground loop.

16. **I'd seen reports that the LW scenario assumes a decrease in temperature in homes by 1degC. Is this the case and if so, what makes you feel that this is credible?**

Yes, we assume a reduction of 1 degree C in Leading the Way and 0.5 degrees C in Consumer Transformation. This is in line with our "level of societal change" axis on the Scenario Framework and (i.e. consumers in these scenarios are more likely to adapt their behaviour in response to price signals or general decarbonisation trends).

17. **Is thermal storage physical or pseudo (thermostat temperature being changed according to the price curve)?**

The thermal storage we refer to in FES is physical (e.g. hot water tanks for phase change material). This is separate / in addition to changes to thermostat settings in some scenarios.

18. **Outputs for thermal properties, H2 Boilers and heat pumps are key for consumer demand, will model assumptions be shared e.g. policy incentives etc?**

Our new spatial heat model was developed as part of an NIA (Innovation) project and so more information can be found not only in our Modelling Methods document (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents) but also here - https://www.nationalgrideso.com/document/190471/download.

19. **Recent data suggest more people heating bedrooms at night. Do you take negative behaviour change into account?**

We don't currently take negative behaviour change into account in any of our scenarios. Steady Progression, our net zero non-compliant scenario is the most like what we see today in terms of energy use and behaviour change, with some changes that are driven by current government policy.

20. **What are the main changes in terms of heat in the scenarios from last year? The level of change seems much less compared to previous years. Is that right?**

Our FES 2021 scenario framework is the same as FES 2020. This is in response to stakeholder requests for consistency and because we believe it still allows us to explore the credible range of uncertainty. The ‘Societal Change’ axis combines changes in innovation, understanding and behaviour. There are some changes to residential and commercial heating outputs this year, thanks to our new, more granular spatial heating model (https://www.nationalgrideso.com/document/190471/download). In terms of assumptions relating to heating in FES this year, we have made changes to residential thermal efficiency assumptions accompanied by increases in the use of heat pumps of all types, as well as changes to the use of thermal storage devices at times of peak demand in homes and businesses. More information can be found in our Key Changes document (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents).

21. What are the reasons for your new conclusion that heat pumps can be less thermally efficient than originally assumed?

It's not so much that heat pumps can be "less thermally efficient" and more that our new FES 2021 analysis shows that heat pumps don't need the very high levels of thermal insulation we previously assumed in order to be more cost effective than other low carbon alternatives. That's not to say that thermal efficiency is no longer important as it should be seen as a no-regret action to support decarbonisation alongside all heat technologies. However, it shouldn't be a prerequisite for heat pumps.

22. What assumption has been made as to who pays for investment in buildings e.g. heat pumps, H2 boilers, insulation?

Our analysis recognises that some level of government support will be required to facilitate the move to low carbon heating - in a similar way to how incentives have helped to stimulate EV roll-out. This will be especially important in relation to retrofits. For new builds, we expect legislation and regulation to play a greater role.

23. What happens to communal/district heating that is currently fuelled by gas CHP?

This varies by scenario in our analysis, but we see a growth in district heating in all scenarios - in part because it is likely to be economic to make use of existing infrastructure. For example, gas CHP converts to hydrogen in System Transformation and bioenergy is a potential solution in schemes were electrification of the main heat source is not feasible.

24. What happens when everyone starts to arbitrage and the peak basically moves from morning and evening to say overnight?

In our longer term modelling we assume that electricity demand starts to move to meet supply from renewables that are largely weather-driven (e.g. wind and solar). In the shorter term, there may be some demand shifting from high demand periods to lower demand periods (e.g. peak avoidance) but this should reflect prices (time of use tariffs) and so we would expect a balance to be reached.

25. What incentive do consumers have to retrofit their existing homes, which is often a necessity to make a heat pump financially viable?

One of the findings from our new FES 2021 analysis is that high levels of thermal insulation may not be required to make a heat pump financially viable. However, it is worth remembering that retrofitting energy efficiency measures will help to reduce ongoing fuel costs for all technologies and so should represent an incentive over the longer term. In addition, we expect some government support to accelerate uptake of energy efficiency measures as we see these as a no-regrets option from a policy perspective (see Key Message 1).

26. What is the standard of insulation now? What improvements are needed for improving building efficiency? If so, what is the cost impact for an average household?

Most homes in Great Britain are around an EPC D level. Improvements need to be spearheaded by strong government policy in order to incentivise uptake of the necessary thermal efficiency measures required. This could be anything from cavity wall and loft insulation, double (or even triple glazing) and solid wall insulation with costs varying dependent on the type.

27. When do you think all new builds will have heat pumps? Were the house building companies' inputs used for your modelling?

We have based our modelling on current government legislation - the Future Homes Standard. This states that all new builds from 2025 must be built to 'greener' standards, including higher levels of thermal efficiency and heat pumps.

28. **Where do you establish your heat pump heating profiles from, as this has huge implication peaks? There is very little publicly available information on this.**

Our heat pump heating profiles are based on robust data from our new spatial heat model, which has been informed by extensive stakeholder engagement (https://smarter.energynetworks.org/projects/nia_nggt0154/).

29. **Will the outputs of the new regional heat modelling be available, either all the way down to LSOA level or at least to local authority level?**

Yes, we plan to add to the information already provided in the Data Workbook by publishing further detail from our new spatial heat model in the next few weeks.

Overall demand (Including Industrial & Commercial and appliances)

1. **It seems strange that Leading the Way requires more demand side change than Consumer Transformation. Have I misunderstood?**

This is down to where the scenarios sit on the framework. Leading the Way assumes higher levels of consumer engagement. This consumer engagement means that they are active in this participation in decarbonisation and therefore are responding at a greater scale to time of use tariffs.

2. **FES 2020 forecast almost no coal use in 2021, yet almost as much has been used this year as at the same time in 2019 and 2020. What will really happen in 2022?**

Our FES output results come from an unconstrained power dispatch model. Under this situation, coal use does indeed drop off very rapidly. This highlights the importance of overcoming network and operability constraints. The ESO has set itself the target of being able to operate a zero-carbon system by 2025 and are making good progress. Each year we publish the Network Options Assessment (NOA) with recommendations of future network re-enforcements. A combination of this work, in addition to increasing the levels of flexibility as per the Operability Strategy Report, will result in a reduction in coal-fired generation and then a reduction in unabated gas-fired generation. This will help to deliver a low carbon power sector whilst maintaining security of supply. More immediately, the capacity of coal-fired generation on the system continues to reduce year-on-year.

3. **Imported biomass = wood pellets for power gen? Any idea where this is imported from, North America?**

In FES we don't explicitly state where we expect bioresources to be imported from (in the scenarios that have imports). Currently, most GB imports are wood pellets from North America (amongst other places) for use in power generation. The most important thing is that the supply chain is demonstrably sustainable.

4. **Who will be exporting surplus bioenergy to UK in 2050?**

We cannot predict who will be exporting bioresources in 2050. It will depend on the levels of global demand and how each country responds to the climate change challenge. However, the most important consideration is to ensure its sustainability – so that it comes from e.g. carefully managed forestry and does not impact ecologically important forests or land required for food.

5. **Are the BECCS figures achievable, given the CCC estimate that we will need to switch over 22% of our agricultural land to biomass growing?**

We have worked closely with the industry (e.g. via FES: Bridging the Gap to net zero) to produce the bioresource ranges used in FES. We have also taken on board feedback from stakeholders since FES 2020 to reduce the amount of BECCS, especially in the power sector and so we have

more “biomass gasification to produce hydrogen” in ST and include “direct air capture or DACCS” in Leading the Way this year.

6. **Last winter coal contributed 10% of demand on some days. With old nuclear unreliable are you concerned about winter capacity margins / high prices?**

Our FES analysis models sufficient generation capacity to achieve the government's security of supply standard of "no greater than a 3-hour loss of load expectation" in all years in all scenarios.

7. **Do we know which industries will use electricity/hydrogen?**

Yes – this is on p74 of the FES document (interactive chart)

8. **Does ESO feel all I&C sectors can be electrified or have potential electric solutions if currently utilising gas?**

As shown on p74 of the FES 2021 interactive document, not all industrial processes can be electrified and so there will be a need for hydrogen or bioenergy to replace current use of fossil fuels. Where this is not workable, CCUS may be required to remove emissions otherwise negative emissions (e.g. greenhouse gas removals) in other sectors will have to offset any residual emissions.

9. **Does your modelling assume that energy efficiencies have continued to occur across the last 18 months or are they weighted towards post Covid-19 recovery period?**

Demand reductions in the very short term are likely to be down to Covid-19 rather than energy efficiency. However, we do expect energy efficiency improvements to continue to drive further reductions over the medium term.

10. **Fire services advise against using appliances at night. People on low incomes often have older/fewer safe appliances. Do you consider this regarding ToU tariffs?**

Safety is always paramount, and care must be taken to avoid a situation where there is a trade-off for consumers between safety and avoiding high prices. As per our second FES 2021 key message, protecting vulnerable consumers has to be at the forefront of rolling out time of use tariffs. On the specific point about older appliances, it is likely that new technology will be needed to respond to price signals and so regulation to ensure safety standards (e.g. around fire risk) will be key.

11. **How are we going to minimize the effect of all smart appliances turning on at the same time to reap the benefits of cheap tariff and low carbon emission?**

This is an important consideration that must be considered when rolling out smart appliances and is something that we highlight in our second FES 2021 key message. Digital solutions (e.g. a degree of "randomisation") will be required to prevent swings in demand caused by multiple smart systems responding to the same price signal.

12. **How do consumers decide when the carbon savings from operating a new appliance outweigh the additional embodied carbon in buying the new appliance?**

This isn’t an area that we model explicitly but it is a behaviour that is likely to be aligned to our “level of societal change” axis on the Scenario Framework (i.e. in Leading the Way consumers may reduce the number of new purchases they make and be more engaged with the relevant trade-offs). While embodied carbon is an important consideration for new purchases, it may be the case that this is outweighed by the lifetime carbon savings of a more efficient appliance - especially if this appliance is produced with its carbon footprint in mind.

13. **How soon are Industries willing to spend on new infrastructure, considering these will have a huge impact on their profits.**

While we expect some incentivisation for I&C consumers in terms of e.g. carbon taxation, energy costs are likely to already be a significant share of their costs and so they may be more likely than

residential consumers to take a longer-term view of costs when considering new infrastructure. The uncertainty around when changes are made is reflected across the scenarios (i.e. energy efficiency improvements are rolled out across the I&C sector quicker in Leading the Way than in Steady Progression).

14. How will these demand factors influence the generation in the future and what's the best possible practice of predicting it?

The main way that demand can influence the generation mix is around the extent that demand can "flex" to meet supply. The more it can do this, the higher the penetration of renewables that the grid can support. In addition, reducing annual demand (e.g. via energy efficiency) will also influence the level of generation required.

15. Is electrolysis included in I&C demand or is it separate?

As we tend to discuss I&C through the "Consumer View" lens in FES 2021, electrolysis demand (which is more of a transformational demand) is not included. However, this information can be found in the "Energy flow diagrams" tab of the Data Workbook.

16. Is the electricity demand for I&C increasing annually? When is the peak?

While this can vary across scenarios and demand sectors, electricity demand tends to reduce in the short term due to energy efficiency improvements before starting to increase as a result of electrification effects (e.g. more so in Consumer Transformation than System Transformation).

17. On the charts for overall demand, the electricity demand seems a lot lower than was quoted yesterday - is the difference hydrogen production?

Yes, several demand definitions are used across the different FES sections. For instance, the lower number may well only be electricity demand at end-consumer level and so may not include transformational demand such as electricity for use in hydrogen production via electrolysis (similar is true for gas demand). The energy flow diagrams on pages 78 and 79 of the main FES 2021 interactive document may be useful to highlight this effect. Where we have quoted numbers (e.g. in the Key Stats in FES-in-5 or in the Data Workbook) we have provided detail on what is and isn't included in the calculation.

18. What are your assumptions on energy efficiency increases in I&C demand? E.G on p49 for residential you have stated the figure of 32% energy efficiency increase by 2030.

In our I&C analysis in FES 2021 we built on our FES 2020 analysis which included the 20% increase in energy efficiency by 2030 from the Clean Growth Strategy for CT and 25% for LW. We also consider the Government's Industrial Decarbonisation Strategy which outlining a route to reduce emissions from industry by two-thirds by 2035 and at least 90% by 2050 compared to 2018 levels.

19. What new industries are likely to emerge in future? Are they being included in your modelling?

Our I&C analysis considers the extent of growth in individual sub-sectors of the economy holistically rather than targeting industries, but this is informed by research and stakeholder engagement on these potential new areas. In addition, we are starting to see connection applications and enquiries in relation to large demand sites such as data centres which are also included in our analysis.

20. Why do you keep using unconstrained grid in your simulations when the difference between your and DEFRAs numbers are so great (almost 50%)?

The carbon intensity of generation figures that we quote in FES comes out of our electricity dispatch model which is run unconstrained to allow downstream processes (e.g. ETYS and NOA) to consider network planning and operability issues without any bias built into the scenarios.

In the short term there are differences between this carbon intensity and what is seen in real life operation of the system (e.g. on the ESO app) due to factors such as network constraints and stability issues meaning wind generation must be constrained off the network, and often replaced with gas. In the longer term we would expect to see these differences gradually disappear as less gas generation is connected to the system and other low carbon solutions are implemented. Reinforcement projects like the Western and Eastern link projects and the ESO goal of facilitating zero carbon operation by 2025 will help reduce these differences.

Flexibility

1. **Can legal requirements for a range of consumer appliances to offer automated flexibility avoid the need for consumer awareness and active participation?**

Yes, as set out in our second FES 2021 key message, smart technology is expected to largely replace active participation from consumers. However, consumers still need to purchase these smart appliances in the first place and so awareness is still required. The important thing is for these types of appliances to be both made available to consumers and their benefits promoted - the extent to which legal requirements on manufacturers are required will depend on how quickly this industry develops. In any case, early engagement with consumers is still vital for decarbonisation, with all three scenarios that reach net zero seeing at least moderate change to consumer behaviour.

2. **Flexibility is the major requirement to accommodate more renewables penetration. National Grid only tender for services. Is HMG moving to incentivise flexibility?**

In their recently published 'Smart Systems and Flexibility Plan' BEIS and OFGEM acknowledged that improvements are required to incentivise flexibility correctly and have taken actions to address this. See https://www.gov.uk/government/publications/transitioning-to-a-net-zero-energy-system-smart-systems-and-flexibility-plan-2021 for more detail.

3. **Are there enough sites to potentially store the 50 TWh of H2 storage in ST?**

We believe that there is enough physical capability out there in terms of suitable geological storage (e.g. salt caverns) but, as per our 4th FES 2021 key message, more focus is needed on hydrogen storage given its likely role in providing whole energy system flexibility. More detail is available in the hydrogen chapter (p105 of the interactive FES 2021 document) where we've also referenced an independent study about available storage.

4. **Aren't interconnectors just cables? In what way do they provide security of supply if GB can't control the flows over them?**

Power flows from low to high prices – if the market is working well, interconnectors can help with security of supply. This is especially the case when there are different generation types available at different ends of the link (e.g. wind vs nuclear vs hydro etc). Currently some interconnectors have Capacity Market contracts which help ensure security of supply.

5. **Do we only get sufficient consumer DSR response through commercial aggregators?**

As more and more consumers move to time of use tariffs there will be increased levels of demand side response from the market. More specifically in relation to grid services, DSR has traditionally been provided by large entities or via aggregators but, as the threshold for participation is reduced, we expect to see increased uptake.

6. **Do you assume there will be any effect of "semi smart" demand where consumers have a simple TOUT and shift demand from tea-time to overnight regardless of need?**

Yes, this type of “static” tariff will likely play a role in the short term (e.g. for EV charging) but we expect more dynamic tariffs to take over in the slightly longer term when prices are more closely linked to renewable output.

7. **Do you think ACS becomes less meaningful when system security needs to build around low wind periods more than high unconstrained demand?**

In terms of security of supply in general, we do think that tight periods could be increasingly related to the supply side – especially weather-driven technology like wind. However, peak demand will still be an important factor and, as more heat demand becomes electrified, cold weather may become more relevant and so starting to look at other metrics (such as the 1-in-20 used for peak gas demand forecasting) may be relevant.

8. **Does "batteries" mean lithium ion or are other battery techs, e.g. flow batteries, considered?**

When we talk about battery storage in FES, we don't specify the type of battery. Lithium ion is currently heavily used but we are aware of other technologies that could also start to play a role.

9. **Doesn't it make more economic sense to store energy as electricity before converting to green hydrogen?**

Due to the conversion losses associated with converting electricity to hydrogen and back to electricity, where electricity storage is appropriate this should be utilised. However, where hydrogen storage is important to the electricity system is in relation to longer term (e.g. inter-seasonal) flexibility.

10. **Exports are described as being of excess energy. Why when we're exporting are we so often also burning coal?**

This is a situation that is likely caused by fossil-fired generation being required for operability or network constraints rather than for energy as renewables will always be ahead of e.g. coal in the merit order due to their far lower short run marginal cost and exports will usually be based on prevailing wholesale prices. The ESO has an ambition to be able to operate a zero-carbon system by 2025 which will significantly reduce these types of occurrence.

11. **Given the significant increase in electricity storage from 25 GWh to over 160 GWh by 2050, what are your views on how to get these large-scale projects to market?**

As highlighted in our 3rd key message for FES 2025, holistic energy market reform is needed to support investment in the flexibility required to operate the future energy system.

12. **Has any consideration been taken to the impact decoupling of the power exchange will have on interconnection?**

Assuming that this question relates to differences between implicit and explicit capacity allocation on interconnectors, this was looked at as part of our work on the UK's exit from the EU and, while implicit allocation (linked to Power Exchange prices) is more efficient, the impact is not significant, and power will still flow as assumed in our modelling.

13. **Have the scenarios been tested across the conditions of different historical weather years as opposed to an average weather year?**

Our modelling makes use of a historic dataset and we do most of our analysis against a tight year rather than an average year. However, we appreciate that we could see extreme weather in the future that goes beyond what we've seen historically and so are working with the parties like the Met Office to consider future extreme weather.

14. **How can we incentivise the significant amount of battery storage required across the scenarios by 2050?**

It's not a silver bullet but changes to the wholesale electricity market (as per Key Message 3 of FES 2021) will help to create arbitrage opportunities as the grid decarbonises.
Also, there will be a role for battery storage in relation to service provision to network operators – local and GB-level.

15. **How does 9-13 GW of Demand Side Response compare to present? What will drive such a large growth? Isn't it cheaper to build storage or peaking generation?**

We currently have less than 2 GW of I&C demand side response (see p144 of the main FES 2021 interactive document) but expect this to increase - especially with increased electrification of heat in CT and LW. This will be driven by a combination of smart technology improvements and a reduction in barriers to entry to the relevant markets. The combination of reducing energy bills by avoiding high-priced periods as well as increased availability of new revenue streams should make DSR more profitable compared to other forms of flexibility than at present.

16. **How have you incorporated the fact that hydrogen has a higher energy density than natural gas in your assumptions around storage?**

Our modelling includes consideration of energy density as well as pure TWh values as this is important in relation to transportation and storage - alongside how it behaves as a gas. The energy density of hydrogen is lower than natural gas. As an example, this is why ammonia is considered as a fuel for the shipping sector rather than pure hydrogen.

17. **How much additional interconnector capacity is projected, especially for Dunkelflaute periods?**

Our scenarios include as much as 28 GW of interconnector capacity by 2040 compared to 5 GW today.

18. **If there is "massive increase" in directional change frequencies of interconnectors, have you taken the ramping constraints of most interconnectors into account?**

The ramp rates of interconnectors are currently restricted to avoid frequency issues when their profiles change.

19. **If you had to describe flexibility in few words, how would you describe it?**

The ability to adjust energy supply and demand to keep them balanced at all times.

20. **In the regional workbook there is 7-9 GW of micro battery storage in 2050 in LW and CT. Is this driven by much bigger home batteries or HUGE domestic adoption?**

Our analysis assumes that the uptake of domestic storage is linked to the uptake in rood-top solar and are sized accordingly.

21. **Most GB imports are currently mostly nuclear (France) and fossil fuels (NL, Belgium, etc.). What happens when they reduce nuclear production or emissions?**

Interconnectors work based on price spreads – questioner is right to point out that there are different generation types across the continent, and we expect power to flow from countries with low prices to those with high prices for a given settlement period. In terms of emissions, we expect EU generation to decarbonise in line with the major announcement yesterday. While there may be some alignment of low carbon technology (e.g. wind) across the continent, we are confident that there will also divergences (e.g. hydro in Norway) as well as benefits of connecting to a larger electricity system.

22. **Networked electrolyser capacity and H2 electricity demand figures in the data workbook suggest load factors of 11-31%. Do the economics work for developer?**

The trade off with these relatively low load factors is that the electricity available for use in electrolysis will be very low priced as it will align with periods of excess generation. Higher load factors would mean that the average electricity price would increase.

23. Someone mentioned yesterday that the negative emission from the carbon capture (BECCS and DACCS) year on year is on the FES doc, cannot find it.

This information can be found in tab NZ.6 of the Data Workbook and on page 38 of the main FES 2021 interactive document.

24. What are the options for storage other than H2? Isn't H2 production & usage relatively expensive and inefficient compared with all the other forms, even battery?

Our analysis includes multiple types of flexibility as one of the key findings is that different types of flexibility are required for different situations. For instance, battery storage is very good at providing fast response but is less suitable for interseasonal storage. It is true that there are inefficiencies associated with converting electricity to hydrogen and back again, but the key point here is that this inefficiency should be outweighed by the value of the energy when it is released (e.g. at a time of high demand and low renewable output).

25. What do you assume about domestic heat storage / heat pump flexibility?

Pages 146-147 of the main FES 2021 interactive document outline our assumptions around residential heat flexibility.

26. What is assumed about the durations of battery storage in the different scenarios? Are they generally 1-2 hours with other techs dealing with longer duration?

Different durations of energy storage provide different benefits to the energy system. Two to four-hour storage typically helps meet short periods of peak demand, excess supply or support grid stability. Longer duration storage can help secure the system over longer periods of high or low renewable generation output. Pages 152 and 153 of the main FES 2021 interactive document include more detail on this.

27. What does the breakdown of flexibility need in daily, weekly and seasonal flexibility? Contribution of Smart Charging, batteries and V2G and hydrogen to each?

In general, all different types of flexibility provision are important – from second by second response (e.g. from batteries) to interseasonal (e.g. from hydrogen). However, the breakdown of need and contribution is not something that we set out explicitly as there is a significant degree of overlap between the different technologies. Instead we set out how much capacity (in GW and GWh) is assumed in the Data Workbook (table FL.X1).

28. What kind of policy/incentive will be needed to increase the demand-side response?

As set out in our 3rd FES 2021 key message, to attract new market participants, especially from the demand side, and to drive efficient signals, the market design arrangements must prioritise accessibility and competition.

29. Where is the 2TWh of hydrogen Storage to be located - and when is it likely to be built?

We haven't modelled the locations of these sites but, as we expect these to be predominantly salt cavern storage, it is likely to be determined by geography / geology to an extent. In terms of when, FES sets out when this storage is required and, due to the nature of these sites, we feel that focus is needed now. This is an area where we would be keen to engage further with industry experts.

30. You show a requirement for dispatchable thermal in all scenarios in 2050 - how would they be financially viable if they are only running for very short periods?

The requirement for dispatchable thermal generation now, as well as in 2050, is to operate as peaking plant or to provide grid services (i.e. rather than running baseload). Therefore, it will be important for revenues to be stacked in a similar way to that of other flexibility providers. This could include high prices in the wholesale or balancing market at times of low renewable output, revenues from the Capacity Market and revenues from the provision of ancillary services to the grid operator – at local or transmission level.

Hydrogen

1. **For hydrogen storage, is it not somewhat misleading to use TWh units instead of volumetric units (cubic meters / feet etc.) given the energy density of H2?**

We have tried to keep the units comparable to those of electricity. When it comes to volume of storage this will depend on the pressure of the gas in storage. This is an area we would like to continue to engage on and understand further as we feel it is an important element of the future energy system (i.e. as per Key Message 4 in the FES document). If anyone would like to engage with us on this, then please get in touch via Box.FES@nationalgrideso.com.

2. **The first half of 2021 has seen daily gaps between demand and wind supply in 100s of GWh. Will hydrogen storage be able to deal with this?**

In System Transformation, which is our scenario with the highest-level use of hydrogen, we have up to 51 TWh of hydrogen storage by 2050. This is paired with 12 GW of hydrogen fuelled power stations. Hydrogen is not our only form of storage as we have included other technologies such as compressed air and liquid air storage. There is also the role of demand side flexibility to consider when managing gaps between supply and demand. The flexibility chapter of the main FES document contains more information on this subject.

3. **We currently consume 50 TWh of hydrogen today in UK, albeit all grey hydrogen. Should this not be labelled low carbon hydrogen?**

As set out on page 101 of the main FES document (interactive version), we do not consider "grey hydrogen" to be low carbon as the emissions associated with producing it from fossil fuels (e.g. natural gas) are not captured. If they were it would be "blue hydrogen". In the short term there is no emissions benefit to using grey hydrogen in the energy sector rather than natural gas and, in the longer term, we use a combination of the technologies in the diagram on p101.

4. **What level of confidence do you have on infrastructure for hydrogen growth?**

Hydrogen production infrastructure (e.g. electrolysers) is starting to grow already. This can be done in a relatively decentralised way. Production of “blue” hydrogen from natural gas requires CCUS and this (development of CCUS) has been an area of focus in previous FES launches. This year we are focusing more on the need for hydrogen storage as this is a key component of “whole energy system” flexibility (i.e. it facilitates excess renewables being converted to hydrogen by electrolysis, stored and then used for peaking generation at a later date).

5. **Is there a proposed roadmap for the development of infrastructure for green hydrogen related production, storage and transportation, especially re: funding?**

The government will soon be publishing its hydrogen strategy, and this will include a lot of information on the roadmap for all types of hydrogen production. How hydrogen is produced in the future remains an uncertainty and so we have included “blue” hydrogen (reformed from natural gas with CCUS) and “green” (produced from electricity using electrolysis) across the scenarios (as well as other methods - see page 101 of the main interactive FES document for more information).

6. **What might be the role for nuclear power both for system stability and hydrogen production?**

We continue to include nuclear generation in FES 2021 - albeit to differing levels across the scenarios and with a combination of large units and small modular reactors. In addition, we have included nuclear for hydrogen production for the first time this year with some co-located electrolysers with nuclear power stations.

7. **Are there any technical/safety issues associated with transporting & using H2 across networks & domestically due to its smaller molecule than natural gas?**

There are several technical issues (including around safety) that are being considered in relation to transitioning from natural gas to hydrogen. For instance, a few innovation projects are exploring this topic to support changes to regulations and network planning and operability etc.

8. **Can you explain the rationale for only blending hydrogen into the NTS in SP given the general view is you would blend regionally <20% into the DN's?**

The reason that blending is only considered for SP is more to do with wider emissions reasons than due to blend limits (i.e. the 20% is the figure we assume). While we are aware of some work being done on blending and de-blending as part of the transition between the fuels, we have adopted a slightly simplified approach in ST and LW.

9. **Can you please clarify, is hydrogen used in the scenarios purely for inter-seasonal storage or do you see a need to support batteries too?**

Specifically, in relation to the electricity system, we expect the main role for hydrogen to be in relation to long term (interseasonal) storage as batteries are more likely to be suitable for shorter term flexibility provision (e.g. daily). More generally, across the NZ scenarios we see a far broader role for hydrogen in other sectors such as industry and heavy transport.

10. **Do we have an idea of regions / clusters in UK that will grow due to hydrogen Production? Does FES have that regional breakdown?**

This depends to an extent on the scenario as in System Transformation we expect hydrogen production (i.e. via methane reforming) to take place in industrial clusters to make use of CCUS infrastructure. In Consumer Transformation and Leading the Way where there is more electrolysis, there is more flexibility around location (although we expect it to be determined to an extent by geological storage proximity for larger electrolysers). We have started to include regional breakdowns in our analysis (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents).

11. **Do you see CT and LW as being driven by distributed production (onsite) or larger hubs with a transportation network required?**

In CT where there is limited hydrogen network, we expect production to be driven by availability of storage and for electrolysers and peaking plant all to be located close to this so that most energy transportation takes place over the electricity network. For LW, as there is more of a hydrogen network, it is more likely that electrolysers will be sited by renewable generation or by existing hydrogen (gas) infrastructure.

12. **Do you see hydrogen-fired generation directly replacing existing gas peakers and CCGTs? Or are they new build?**

Following engagement with stakeholders, whilst it is technically possible for existing generation to be retro-fitted to run on blended gas we expect most of the dedicated hydrogen generation to be new build (albeit located at existing sites) and optimised for peak running.

13. Does HMG CCUS policy (clusters) lead to favouring certain FES scenarios for hydrogen over others, e.g. better vfm of ST given CCUS infrastructure tending to SMR?

In general, and following discussions with stakeholders, we believe that electrolysis is likely to dominate over methane reformation in the later years of the scenarios and that the role of latter to be more important in terms of establishing a hydrogen economy in the nearer term where it is more cost competitive. That said, electrolysis does have some additional benefits such as the ability to be installed quickly (methane reformers have a longer lead time and seem to rely more on central support) as well as offering more whole energy system benefits.

14. From your analysis do gas connection bans for new-builds make sense; considering the low demand and high proportion of upfront costs possibly suiting h2?

In our analysis we assume that hydrogen-ready boilers are installed in System Transformation due to the use of hydrogen for residential heating in this scenario. The ban makes sense in a similar way to the ban on petrol and diesel vehicles in the transport sector.

15. Given that car drivers worldwide have had the same common approach to fuel since Henry Ford, why not use H2 for cars, trucks, ships, energy storage, etc?

While System Transformation includes some hydrogen for private vehicles, in our analysis we expect it to be used more for larger and heavier vehicles where energy density is more important, and which can make electrification challenging. Certainly, the ranges and charging times of new EVs are improving constantly and so it is difficult to see hydrogen cars gaining a foothold (in the UK at least). They also provide a lot of short-term flexibility to the system which is more complicated with hydrogen.

16. Have you incorporated insights on the water needed for hydrogen production?

We do not currently see an issue in relation to water supply for hydrogen production at a GB level but there's potential for it to be an issue locally if electrolysers aren't sited with water in mind.

17. If we have H2 storage in the scenarios, surely the high prices required to make low load factor electrolysers profitable won't occur?

Assuming that I've understood the question correctly, the storage will have to be filled by hydrogen that is produced somehow and, depending on the scenario, this may be by electrolysis.

18. In ST hydrogen electricity generation totals 12 GW, yet it is generating 0.7 TWh - a capacity factor of 0.63% (or 55hrs/yr operation). What's the market incentive for that?

We assume that this generation will be able to claim a high price for its output as it will mostly be generating at times when electricity demand is high and renewable output is low. In addition, it will be able to supplement this with revenue from Capacity Market and Ancillary Service contracts.

19. In ST, what is the rationale for hydrogen growth to be "Blue " rather than "Green"? Is it about cost or something else?

In System Transformation, large volumes of hydrogen are required due to its use in residential heating. Initially we expect that blue hydrogen will be able to scale more effectively than green hydrogen and is also likely to be more cost-effective early in the FES period (although we expect this to change nearer to 2050).

20. In ST, you assume ~11 GW of BECCS in the power generation sector, what additional bioenergy capacity is assumed to produce the BECCS H2 in this scenario?

ST has 135 TWh of bioresources going to power generation (the vast majority of which is BECCS), compared to 55 TWh of bioresources used to produce 43 TWh of hydrogen.

21. In terms of hydrogen production, what are the main differences between FES21 and FES20?

The main difference between FES 2020 and FES 2021 in terms of hydrogen production is that there is less in FES 2021 in ST and LW compared to FES 2020. In addition, ST 2021 has more biomass gasification than ST 2020 and there is also some nuclear electrolysis which is new in FES 2021. Please see our Key Changes document for more information (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents).

22. Is it right to assume the gas network will be used for hydrogen? Or do we need a separate infrastructure?

This depends on the scenario. In System Transformation we assume full conversion of the gas network to transport hydrogen, both transmission and distribution networks, whereas in Consumer Transformation hydrogen demand is low and this is not likely to be needed. In Leading the Way, we expect a regional approach, with gas distribution networks retained in most areas to deliver hydrogen. We don't expect to see separate parallel hydrogen transportation infrastructure built alongside the existing gas network. Instead, interim solutions such as hydrogen blending and de-blending from the natural gas network may be able to help smooth the transition to hydrogen.

23. Is nuclear electrolysis from dedicated nuclear plant or co-located site (with power to the grid sometime? Is this small nuclear units or traditional large ones?

Nuclear electrolysis is from electrolysis plants collocated 'behind the meter' at nuclear sites that allow nuclear plants to operate at constant full capacity, even at times of low demand by ramping up to use the excess electricity. In Consumer Transformation this is primarily smaller reactors, whereas in System Transformation it is mostly large traditional nuclear reactors.

24. Is storage capacity of H2 the biggest hurdle for hydrogen growth given the availability of suitable caverns and the poorer volumetric density of hydrogen?

Hydrogen storage is one of many challenges that must be met before hydrogen use can become widespread. A recent study (https://ukccsrc.ac.uk/wp-content/uploads/2020/05/John-Williams_CCS-and-Hydrogen.pdf) indicated that there is a theoretical capacity of up to 3,000 TWh of hydrogen storage, although if small sites are discounted this drops to 200 TWh. This significantly exceeds the maximum hydrogen storage modelled in our scenarios. The development of storage will take time however, and the timescales for developing these storage sites and dealing with planning procedures, environmental impact assessments and geological engineering work are an important consideration.

25. LW has imported H2, why have you made this assumption considering EU aims to also be importing significant amounts of green H2? Best for UK to be an exporter.

In Leading the Way, we assume the development of an international market for hydrogen import and export by 2040. The scenario has a relatively high hydrogen demand, but no production associated with the continued extraction of fossil fuels, and therefore requires some level of hydrogen import and export is likely to be helpful to balance supply from electrolysis.

26. The CCC found that between 15 - 90 TWh of I&C fuel consumption could switch to hydrogen. Why has so much I&C demand (141 TWh) been allocated to hydrogen in ST?

We have benchmarked our modelling against other sources such as the CCC, however in ST the full conversion of the gas network to carry hydrogen allows a very high level of I&C demand to switch from natural gas to hydrogen (i.e. this is our "high hydrogen" scenario). The infographic on page 74 of the main FES 2021 interactive document shows the processes that we have modelled as being suitable for conversion to hydrogen.

27. The profile of hydrogen storage looks very different across the scenarios - what do you see providing these; particularly in LtW where there are rapid cycles?

We expect salt caverns to be the primary method of hydrogen storage in all three net zero scenarios. This may be supplemented by tanked hydrogen storage for faster response times, particularly where this may be co-located with hydrogen production technologies. Leading the Way may also be able to feed hydrogen into the converted gas network in some areas of the country.

28. The South Wales industrial steel hub would want H2, but no significant energy solution is obvious, has a tidal barrage in the estuary in consideration still?

The latest position from Government is that it is not economic to develop and so the project has stalled. We will monitor the situation and adjust our scenarios in future if it looks like a tidal barrage or tidal lagoon project is likely to be developed.

29. What form of hydrogen is assumed used in aviation and shipping? Is it converted to other carriers? if so, are energy losses and subsequently costs assumed?

Hydrogen may be converted into ammonia or other synthetic fuels for use in the aviation and shipping sectors. We don't model this explicitly, but just consider overall hydrogen demand for these sectors in line with CCC assumptions.

30. What if the assumptions around industrial hubs moving to H2 to create H2 for domestics disappears with I&C electrification? E.g. what if the hub doesn't exist by 2030?

If these hubs don't materialise by the projected dates, then alternate means of decarbonising residual I&C emissions would be needed. In the Consumer Transformation scenario which has less hydrogen, there is more reliance on industrial CCUS for example.

31. What is the potential to reduce the cost of H2 production with high temperature electrolysis with waste steam, e.g. from power stations?

This is a topic that we'd like to explore further and so would appreciate any further detail that is available (e.g. the extent to which this approach might work with nuclear generation) - Box.FES@nationalgrideso.com.

32. When does the latest the Govt policy need to be made legislation, including planning requirements, to allow the Leading the Way scenario to be achieved?

It is difficult to provide a single date as there are several different policies that will require legislation to allow the timescales set out in Leading the Way to be realised. The policy timelines on pages 43 and 77 of the main FES 2021 interactive document may provide some context to this question.

33. Where can we find information on the capacity (MW) of methane reformation with CCUS for the different scenarios?

In the main FES 2021 document and Data Workbook we have only provided information of annual TWh production of hydrogen from each source, and total MW capacity for all production technologies. Please get in touch if you would like any more detailed information on this and we can share this with you (Box.FES@nationalgrideso.com).

34. Why does biomass gasification play a smaller role in leading the way scenario? Gasification seems attractive considering its economics and negative emission.

There are only limited amounts of bioresource available, and a range of sectors competing to use them. Leading the way has a range of sources of hydrogen including networked electrolysis, non-networked electrolysis, hydrogen import and biomass gasification, and competing demand for bioresources from power generation, I&C, aviation and residential uses. We increased the proportion of "hydrogen BECCS" to "power BECCS" in terms of greenhouse gas reduction in System Transformation but will consider this for Leading the Way too.

Electricity supply

1. **The capacity of non-networked offshore wind has not been explicitly defined in any of the scenarios. Can you provide more insight on this please?**

There is 23.4 GW of non-networked offshore wind for hydrogen production. Annual energy (TWh) from this non-networked offshore wind can be seen on p106 of the main document. Capacity (GW) information can be found in table ES1 of the Data Workbook.

2. **Key Message 4: do we need better integration of planning between offshore generation, interconnectors and reinforcement?**

Yes, as we set out in the document, offshore coordination is important and includes not only offshore wind and interconnectors but also potentially hydrogen. Our future energy scenarios feed into the ETYS and NOA process that inform network reinforcement.

3. **Does the UK have the onshore capability and capacity to fulfil future energy generation needs i.e. supply chain including manufacturers, construction etc?**

As set out in our 4th Key Message, it will be important to ensure we have the ability to transport energy from where it is generated to where it is consumed – onshore and offshore. In the UK we have established processes for this (ETYS, NOA) and are also working alongside industry stakeholders on offshore coordination and onshore competition to ensure that network reinforcement work is as economic and efficient as possible.

4. **Regarding off-network generation, why would a generator cut off its access to the electricity market to save the small % of project costs on a grid connection?**

There are several reasons why a generator may choose not to connect to the network. For example, it may be connected to a private wire if it is powering a single site, or as in some cases in the FES analysis, the generator may be powering an electrolyser to produce hydrogen. This hydrogen may then itself be distributed by a gas pipeline network.

5. **Are the generation capacities by technology by year in the data workbook the average operating in that year or the amount operational on 1st Jan of that year?**

Capacities are as of 1st October that year, i.e. in place ahead of the winter.

6. **Do you expect wholesale electricity prices to be more volatile? More -ve prices in summer and high spikes in winter on low wind days? How wide will this be?**

Yes, we expect the wholesale price to be more volatile in the future as it is increasingly set by zero-marginal cost renewables (i.e. seeing low prices when there are high levels of wind and solar generation output and higher prices where there aren't). The future of wholesale prices will also depend on market reform as electricity markets will need to change in future to accommodate a system with high levels of renewable generation. The ESO is doing work on this, and we recently published a Markets Roadmap (https://www.nationalgrideso.com/research-publications/markets-roadmap-2025) setting out how things may need to change.

7. **Do you include tidal stream?**

Yes, we do model tidal stream. These figures are aggregated into the Marine category in the data tab ES1 in the data workbook.

8. **Do you see much growth in non-solar and wind renewables like hydro, geothermal, tidal, wave and anaerobic digestion? Or have wind and solar effectively won out?**

We expect the cost reductions of wind and solar to lead to these technologies continuing to dominate over other renewables. Other renewables including hydro, marine, geothermal etc. more than double compared to today in Consumer Transformation and System Transformation but see

lower growth in the other scenarios. They do, however, represent a small share compared to offshore wind, which increases ten-fold in Consumer Transformation by comparison.

9. **Has any comparison of year on year FES generation capacity been made? What have you learnt from this?**

We have looked at some historic comparisons. In some cases, we have observed that in year 1 and 2 of the forecast a few existing sites have remained on the system when we expected them to drop off earlier due to high margins. We adapted our process to allow for this and then transition to a margins / loss of load expectation standard in later years. We also publish a comparison document alongside our main FES document each year considering year on year changes (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents.

10. **How are the negative emissions from BECCS accounted for? Presumably the negative emissions are realised over several years after generation as new biomass grows.**

Emissions are accounted for in the year of combustion, accounting for the carbon that was absorbed through the lifetime of the biomass. We believe this is in line with other organisations but are keen to receive any information in this area that might allow us to improve our modelling.

11. **How have you modelled carbon prices? Have you used the UK ETS and what load reduction factor (LRF) has been assumed?**

Our carbon price modelling happens early in our modelling process, and at the time the modelling was carried out the UK ETS hadn't held its first auction. The results of this auction (which we have since seen) were in line with our assumptions, which we based on EU ETS figures. We don't make specific assumptions of an LRF and instead take a long-term view of what carbon prices may be necessary to deliver emissions reductions.

12. **How much new capacity of nuclear is expected to come online post Hinkley ptC?**

This varies per scenario, and ranges from 0.5 GW more in Leading the Way through to 12.1 GW more in Consumer Transformation.

13. **I noticed there is still a lot of waste (and waste CHP) generation in the net zero scenarios. Incineration of waste is not compliant with net zero - unless CCS?**

We have some CCUS from waste in the figures that come through from the CCC in relation to emissions and we incorporate this into our analysis.

14. **If the range for 2050 often falls outside the previous year's FES, how can it be said the FES covers a large proportion of the credible range?**

This is a good observation and one that we are aware of. It is also the reason that we produce FES on an annual basis as a lot can change in some years - especially around the policy angle (e.g. this year saw the 10pt plan and Energy White Paper). We try to use the word "credible" as it is difficult to capture all possible changes between now and 2050. Also, to fully capture every possible iteration would require many more scenarios that would cause issues to our downstream customers just in practical terms. We are especially keen to hear any more feedback in this area so that we can improve for next year.

15. **In terms of electricity production, what are the main differences between FES21 and FES20?**

Specifically, in relation to electricity supply, while there is variation across the scenarios, there is generally more offshore wind across the board as well as more BECCS capacity (for same output). More information can be found in our Key Changes document (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents).

16. **Is there any measurement of likelihood with each scenario? Which is the most likely to be followed? How likely is it we will meet Net Zero?**

We don't give a likelihood for each scenario as they are designed to cover a credible range of uncertainty between them. There is a lot of work going on in order to meet net zero, and our scenarios show this is possible. However, we still consider it credible that the net zero target is missed, and hence continue to include Steady Progression which decarbonises over time but doesn't meet net zero as progress stalls in areas such as heat. This is an assumption that we will reconsider and discuss with stakeholder ahead of the next FES publication.

17. **Part of the long lead time for large nuclear, relates to reactor and site safety approvals, won't this present a challenge for SMR? What needs to change?**

There are a range of challenges to delivering new nuclear, we assume SMRs will typically be delivered on existing nuclear sites, reducing some of the hurdles required. We recognise the long lead times required and therefore don't expect any SMR development until the 2030s. In terms of specific changes to the process, we'd welcome feedback from nuclear industry experts on this.

18. **Short term ranges for generation presented in the FES in the past have been quite narrow. Given the use of FES for the Capacity Market, is this appropriate?**

Given the timescales for new generation build, the range is naturally lower for shorter timescales and, in Capacity Market related work, can often be more to do with assumptions around closures than new plant. In addition to the uncertainty captured by the FES scenarios, the analysis that supports the Capacity Market includes further sensitivity analysis around non-delivery and early closures.

19. **ST and even CT still has some unabated fossil fuelled electricity generation in the 2040s. Is this gas reciprocating engines or something else?**

This is primarily a mixture of CCGTs and distribution connected gas reciprocating engines, along with some gas CHP.

20. **To what extent are the NZ compliant scenarios back solved rather than actual realistic pathways given the use of undeveloped technology?**

CT and ST are "back-solved" to meet the net zero target in 2050 exactly. However, LW and SP are modelled without this constraint and show faster, and slower pathways respectively based on our assumptions about how rapidly change can be delivered in different areas.

21. **What is the additional electricity supply required to satisfy heat pumps in the highest scenario? Cons Transform (26 million HP)**

Chart CV.9 shows annual electricity demand for home heating, in the highly electrified Consumer Transformation scenario this increases from 25.3 TWh today to 86.8 TWh in 2050. The additional electricity supply required depends on the technologies used to deliver it and the load profile, but as an equivalent, 61.5 TWh would require approximately 14 GW of offshore wind generation, only 12% of the installed capacity of offshore wind in CT in 2050.

22. **What load factor does your analysis indicate of electrolysers? Is there a risk that low load factors will undermine the economics of green vs blue H2?**

We see load factors between 19 and 36% for electrolysers in 2050. Green hydrogen is most useful if it can provide system benefits as a form of flexible load, and for economic reasons we would expect it to primarily run when electricity prices are low to minimise the production costs of hydrogen. We don't expect very high load factors for electrolysers to be economic if this would involve running on high cost electricity at peak times.

23. **What proportion of the true credible range do you think the FES covers? Projections for 2050 seem to vary notably between publications.**

We try to capture the credible range of outcomes (holistically across the scenarios rather than just for an aspect like generation). We rely on stakeholder feedback to highlight if this range gets too narrow.

24. What's your take on the carbon emission from interconnectors in the future and from carbon capture? Cannot find a year on year value for carbon capture.

In FES we follow similar carbon accountancy rules for interconnectors to the CCC, IPCC etc and assume zero for both imports and exports. More info on likely carbon flows can be seen via the ESO app though (https://www.nationalgrideso.com/news/introducing-our-carbon-intensity-app). For carbon capture, negative emissions by year can be seen in NZ.6 (p38 of the FES 2021 interactive document) and generation with CCUS can be seen in SV.33 (p123).

25. Why do you show "storage" as GW when the critical factor is GWh i.e. the capacity, not the dispatch rate? Large batteries are incredibly expensive.

The Electricity Supply chapter focuses on GW capacity of technologies and annual generation output. GWh storage doesn't entirely fit into either of those, so we cover it in the Flexibility chapter which is where we consider the behaviours of flexible technologies and how the system as a whole fits together. Both GW and GWh are important considerations for storage.

26. Why doesn't the annual carbon emission from the FES document and the annual average of the half hourly emission from National Grid website match up?

This is all to do with the fact that the FES figures come from our dispatch model which is based on an unconstrained dispatch (e.g. it doesn't assume that say wind is constrained off to be replaced by fossil output due to network constraints). We acknowledge that this gap exists but believe that it should narrow as the grid decarbonises. This approach is important for other processes such as NOA and ETYS which consider the impact of unconstrained flows on the network and what reinforcement may be needed.

27. With N Europe all moving to high wind gen mixes, how realistic are the interconnector import projections on low wind days and when constraints are included?

An advantage of connection to mainland Europe is the small-time lag between peak demand in GB and demand peak demand in Europe, this offset allows us to enjoy flows from Europe at peak GB demand even in high wind scenarios. There are rare periods where there is extremely low wind and solar both Europe and GB known as dunkleflaute periods. It is times like this which are why we model our scenarios with other forms of flexible generation available out to 2050 such as hydrogen powered generation. We run a pan-European dispatch model to consider electricity flows across Europe as part of our modelling.

28. You rely a lot on tech that doesn't exist. What if gas+CCS is never made to work? Or CCS more broadly? What if SMRs are never viable?

This is one of the challenges of FES as we are trying to consider technology that could be there in 30 years' time (e.g. think back to technology in 1991). We try to find a balance between including technology that is likely to play a role (even if not commercially viable now) and not including tech that has too low a "Technology Readiness Level". This is an area where we are especially keen to receive feedback (i.e. are there potential technologies that we should be considering that are not included in FES 2021)

Whole system

1. **16 GW of interconnectors by 2030, from around 5-7 GW now. Appreciate this is a scenario but how feasible is that given the short timeline?**

Our analysis on interconnectors is largely based on projects that are already in the pipeline (I.e. they are not “dummy” projects) and the scenarios apply a range to the expected dates from sources such as the ESO’s Interconnector register and the equivalent from European TSOs. We assess the use of the interconnectors via our economic dispatch model and have incorporated learnings from the Network Options Assessment for Interconnectors (NOA IC) back in to our scenarios.

2. **Have you done any costing of these scenarios? What level of investment p.a. is required (sectorally or total across whole system) to achieve these scenarios?**

This year we are not proposing to carry out the same costing for our scenarios that we did last year. The scenario framework has not changed this year and there are no large updates to the background costs included in the published costings of FES 2020. There was very little variance between the scenarios and therefore we are focussing our efforts on other areas such as our regional analysis.

3. **Does Steady Progression assume that current government policy is implemented but not much else?**

Steady Progression represents what we see as the credible least amount of progress towards net zero.
As a crude summary, it assumes that power generation and private road transport is largely decarbonised but that the arguably more difficult areas of residential heating and industrial processes are not decarbonised and so the net zero target is not reached in 2050.

4. **What is your view on where are we heading? Is each scenario equally viable or does the rate and drivers of change suggest one/few is more likely than others?**

There is too much uncertainty in the future for a credible single view of the future energy system out to 2050, or to say one scenario is more likely than the other. Scenarios are a powerful tool for understanding uncertainty and developing strategy accordingly. By providing a range of credible futures, we can be confident that the reality will be captured somewhere within that range. However, we do provide a 5-year forecast; including by technology type which can be found in the Data Workbook.

5. **You provide some high-level recommendations but stop short of what policy could be - is that due to scenario uncertainty or uncertainty about role of ESO in leading this?**

The purpose of FES is to set out what the future of energy could look like in certain scenarios. However, our "FES: Bridging the gap to net zero" programme takes a closer look at what needs to be done to reach the UK’s 2050 net zero target. We intend to bring together a wide range of stakeholders to progress the debate and recommend actions for policymakers and industry to move towards net zero. More detail can be found here https://www.nationalgrideso.com/future-energy/future-energy-scenarios/bridging-the-gap-to-net-zero.

6. **Within 'whole systems' where does energy for water purification and distribution feature?**

The energy requirements of the water industry are captured within our I&C (Industrial & Commercial) modelling. More generally, we don’t focus explicitly on water supply in our analysis, but it is certainly an important component of the wider whole system (e.g. there is a requirement for water in the electrolysis process, but we don’t currently anticipate a supply issue).

7. **Does the analysis for system resilience include the potential impact of climate change on extreme weather events? Are new tools needed for resilience?**

We account for extreme weather events based on historic weather patterns when calculating peak demands. In addition, elements of our modelling include climate-adjusted weather data. We also engage with stakeholders including the Met office and National Infrastructure Commission regarding

climate impacts and future weather events as we acknowledge that these may not have been experienced before (i.e. use of historical data is not enough).

8. **Thermal storage is providing large amounts of demand reduction across the net zero scenarios. Is this discrete thermal storage & how long is the DSR window?**

Discrete thermal storage such as hot water tanks and dedicated 'thermal blocks' form part of our residential heat flexibility alongside uses of hybrid heating systems and switching off heating for short periods of time in well insulated homes (e.g. in line with Time of Use Tariffs). We assume a window of around 3-4 hours (see p146 of the main interactive FES document for more information). The DSR window varies to allow the peak demand to be managed as needed.

9. **Can we see a pathway for decarbonisation for I&C for key industries and alternate fuels they need to be switching?**

Pages 66 - 75 of the main FES document, and CV.43 to CV.56 of the data workbook provide information on the decarbonisation of the Industrial and Commercial (I&C) sectors for each scenario. This includes annual demand by fuel type (electricity, natural gas and hydrogen), and annual emissions for industrial and commercial heat. P74 shows fuel switching options for different sub-sectors. NZ.5 in the Data Workbook provides the total annual emissions by sector for each scenario out to 2050, and includes emissions for industrial process, industrial heat and service heat.

10. **Does FES cover demand requirements for new industries like data centres, giga factories**

Yes, data centres are included within our I&C (Industrial and Commercial) modelling. The analysis uses a combination of sector level growth assumptions and specific projects when connection information is available (e.g. in the case of some data centres). In addition, where appropriate the location of these types of large demand sites s is also considered.

11. **Competing future demands for feedstock/fuels, who has the ultimate say in a more integrated whole system? Joint system operator or will markets decide?**

As set out in our 1st FES 2021 key message, delivering a net zero energy system will require a combination of competitive markets and coordinated and strategic planning.

12. **Is CCUS only located in the low carbon clusters?**

Due to economies of scale and the likely need to connect to pipeline networks for CO2 transportation, we expect the majority of CCUS to be located within the low carbon clusters. However, there could be examples where this is not the case (e.g. smaller scale operations or where the carbon is "used" rather than stored perhaps).

13. **Do you factor in the emissions associated with UK imports (for example the associated emissions of a large vol of biomass) into your net zero scenarios?**

We follow IPCC accounting when considering imports and exports (e.g. biomass or electricity) such that emissions are recorded where they take place. This is like how consumption emissions are treated (e.g. emissions associated with the production of goods consumed in the UK are accounted for where they were produced). Bioenergy has its own rules under international carbon accounting and is deemed to be carbon neutral (see p85 of the main FES 2021 interactive document for more detail).

14. **In the key comparison chart, you have 26 CCUS power stations for ST. Does this include bioenergy & natural gas? What is the average capacity for these stations?**

Yes, the 26 includes both bioenergy and natural gas and the capacities are broadly similar to existing fossil plants (e.g. stations made up of c500 MW units).

15. How do the network costs compare for hydrogen for heat compared to electrification?

As set out in the FES 2020 costing report, hydrogen network costs are comparatively low comparing to those of electricity. There is a mixed approach across the scenarios, with some scenarios blending hydrogen and gas in the existing gas network, some areas where the existing gas network is repurposed to carry hydrogen and others where new dedicated hydrogen networks are needed. The ability to repurpose existing infrastructure reduces overall costs.

16. Has your modelling factored in the implication on Offshore and onshore wind deployment due to the TNUoS reforms taking place e.g. higher tariffs in Scotland?

In a similar way to how we produce FES supply and demand information based on an unconstrained system (so that bias is not introduced ahead of downstream network and operability analysis), we don't explicitly model code-related effects such as TNUoS reforms in the long term as these could change. However, in the shorter term this type of effect is something that we consider in our generation capacity analysis.

17. What H2 boiler efficiencies have you utilised and scale / size assumptions on H2 electrolysers?

We assume an average efficiency of 87% for hydrogen boilers. See p104 of the main FES 2021 document for more information. In terms of electrolysers, whilst economies of scale will be relevant for large sites such as those involving dedicated offshore wind, one of the advantages of electrolysis over methane reformation is that it can be rolled out on a smaller scale.

18. Where on the FES website is the 2020 costing information? Does not appear to be with the main documents.

FES 2020 costing information can be found at the following link - https://www.nationalgrideso.com/document/181961/download

19. From my work on this, it appears this is hugely sensitive to peak heating demand therefore actual HP profiles, which there is little info on. Any view on this?

The profiles (including the role of thermal storage) can be found on p54 of the main FES 2021 interactive document. More information on assumptions in our new spatial heat model, please see https://smarter.energynetworks.org/projects/nia_nggt0154/

20. What magnitude of cross-sectoral flexibility are you envisaging? E.g. How much electricity demand reduction is there from heat pump flexibility and EV charging?

Figure FL.8 on p143 of the main FES 2021 interactive document shows the relative impacts of different demand side technologies. This equates to 26.5 GW in Consumer Transformation. More information on cross-sectoral flexibility can be found on p140-142 of the document.

21. Are carbon offsets (from outside territory) allowed in any of FES scenarios? If so, would this have reduced the amount of BECCS or DACs that you have included?

No, we don't use carbon offsets from outside of the UK in our analysis and follow the same carbon accounting used by the IPCC and CCC etc.

22. Have behavioural economic studies been carried out to understand the willingness or level of incentive need to get domestic customers to participate?

Rather than carry out behavioural economic studies for our scenarios, we instead try to capture the uncertainty in this area by applying our "level of societal change" axis. We would be keen to access the results of any such study if this is possible please?

General

1. **Your FES 2021 relies on CCS when it can only capture up to 95% CO2, so do you agree that it should be phased out by 2050?**

CCUS is present in all scenarios although used in different ways. It is possible not to have gas CCUS in the power sector and still reach net zero, as in Leading the Way. However, it is still needed for some industrial processes that require natural gas. Additionally, BECCS makes up the largest proportion of negative emissions in all scenarios and is used for security of supply in the power sector. Therefore, under the current credible suite of technologies it will be very challenging to meet net zero without CCUS.

2. **FES 2020 stated that net zero could not be achieved without BECCS. Is that still true?**

We use BECCS across several sectors in all our net zero scenario to help achieve net zero. This is because it can provide the negative emissions required to offset residual emissions in hard to abate sectors such as aviation and agriculture.
Following stakeholder feedback, we have reduced the reliance on BECCS in the power sector relative to FES 2020 but negative emissions are still required from somewhere and so all of our net zero scenarios include this technology (in addition to high levels of nature-based solutions such as afforestation, deforestation and peat restoration). We worked with a wide range of stakeholders including the CCC when we created our scenarios to ensure the assumptions used were robust.

3. **How much unabated (without CCS) bioenergy is included in the power sector in 2050 in these scenarios?**

There is 5 GW of biomass generation capacity (not including BECCS) in Steady Progression and less than 1.5 GW in the net zero scenarios.

4. **Alongside the GSP locations in power demand can you add the LA to the key please**

Our visualisation of the regional breakdown of electricity data is new this year and we are keen to solicit feedback on this. We will be collating feedback like this suggestion in preparation of a review for FES 2022.

5. **Of the back of these scenarios and recommendations, what will National Grid being doing to help fill the gap to net zero 2050?**

Our FES: Bridging the gap to net zero programme takes a closer look at what needs to be done to reach the UK's 2050 net zero target. Through the programme, we identify and investigate the areas from our FES work that we consider to be the most important and the most uncertain. More detail can be found here (https://www.nationalgrideso.com/future-energy/future-energy-scenarios/bridging-the-gap-to-net-zero).

6. **Who needs to lead the campaign to engage consumers? What role can ESO play in it?**

It is important that whoever leads this campaign is a trusted and independent commentator. We don't currently see the ESO necessarily taking this role but are very willing to support in whatever way we can with this important work!

7. **As H2 cannot be transmitted at high pressure (no compressor exists) are you assuming Local Production Local Use? As advocated by my Gas Expert contact.**

This depends to an extent on which of our scenarios we are talking about. In System Transformation we assume high pressure hydrogen transmission (either dedicated or repurposed NTS assets). However, in Consumer Transformation we assume more local production of electricity as well as more local transportation.

8. **How realistic is high consumer engagement? 7% adults never used the internet; 16% have low literacy; 17m have low numeracy, 14% households in fuel poverty.**

We recognise that consumer behaviour is pivotal to decarbonisation, although at the same time any transition must protect those consumers who cannot engage with new technologies. Consumer engagement with new technology is uncertain. The 'level of societal change' axis on the scenario framework aims to capture this uncertainty. However, as we state in our second FES 2021 Key Message, the journey to 2050 will include multiple generations of consumers and so there is significant opportunity to increase engagement from current levels if we act now to address these issues.

9. **What learnings can be taken from the experience of smart meter roll-out regarding the topic of consumer engagement with the energy system?**

The main learning from the smart meter roll-out in relation to consumer engagement more generally (as well as smart tech more specifically) is that technological and compatibility issues need to be minimised to allow for a smooth roll-out and that consumer education is required to ensure that the benefits are understood and that concerns (e.g. around data privacy and impact on user experience) can be allayed.
Building data from Smart Meters into our analysis is an area of our modelling development. Projects are ongoing to assess the potential availability and use of this type of data. We are looking forward to being able to use this data to better understand consumer engagement.

10. **With all these changes, what impacts do you envisage on the power quality of the grid?**

There are operational complexities associated with replacing fossil fuel generation with renewables. However National Grid ESO is working hard to ensure it can operate a zero-carbon grid by 2025, more detail on how is provided here https://www.nationalgrideso.com/future-energy/cop26/road-zero-carbon.

11. **Can you publish the workbooks with the formulae in so we can see how different areas interact directly?**

The Data Workbook is populated using our model outputs which do not always come from MS Excel. This means there are often no formulae to add to the data workbook. However, there are some instances where formulae could be added, and we are looking into doing this next year.

12. **Irish market seems 5 years ahead with managing a-synchronous system with low inertia by prioritising these plants to allow RES to run. Is ESO going to do similar?**

National Grid ESO aims to be able to operate a zero-carbon grid by 2025, more detail on how is provided here (https://www.nationalgrideso.com/future-energy/cop26/road-zero-carbon). The GB electricity system continues to break records for renewable output without priority dispatch for RES and so this is not something currently being considered.

13. **What is BECCS?**

BECCS stands for Bioenergy with Carbon Capture and Storage and is used in all our net zero scenarios.
It is where the emissions from energy produced from bioenergy (which is deemed to be carbon neutral by the IPCC, CCC etc) are captured using CCUS technology. This allows negative emissions to be generated. See page 26 of the main interactive FES document for more information. Our FES analysis has identified sectors (e.g. aviation, agriculture etc) where it does not appear possible to eliminate all greenhouse gas emissions and so negative emission schemes such as BECCs will be required.

14. What are the main approaches to managing seasonal variation in demand/supply as renewable components of generation increases?

We will end up with an electricity system where supply is much more variable throughout the year, so sometimes supply may be too high and at others too low. Potential options to manage this include energy storage, interconnection and gas back-up (either with CCS or hydrogen). However, there is also a significant opportunity for more demand side flexibility.

15. What is the ESO view of other reports on net zero, for example CCC reports? How many of the recommendations are being considered in FES?

We work closely with the CCC when developing FES to ensure that our assumptions around areas outside of our expertise (i.e. non-energy related areas) are robust and that we understand and can explain any differences.

16. It would be useful if the scenario data was at local authority level, to engage with local government.

In FES 2021, based on stakeholder feedback, we have begun to take a more regional approach, for example with the development of our regional heat model. This regional approach is an area we are putting greater resource into for the future and this will allow us to publish more robust data at greater geographical granularity (e.g. local authority level where appropriate).

17. When does the next Bridging the Gap get released?

The next Bridging the Gap final report will be published in March 2022.