Resource adequacy in the 2030s

December 2022

Foreword

Net Zero is one of the biggest challenges of our generation. The threat of climate change is real and has mobilised Great Britain (GB) to deliver one of the fastest decarbonising electricity systems in the world. By 2035, the Government has set out a target to be able to run a fully decarbonised electricity power system all of the time[1]. This will mean reducing our reliance on fossil fuel generation and transitioning to a system that operates with renewables and low carbon energy resources.

It is essential that we understand the potential risks that this transition may bring in delivering secure electricity supply to consumers. This is a world in which secure supplies will be paramount for consumers in their daily lives through increased digitalisation, as well as growing dependence on electricity for transport and heat.

There will be much higher volumes of weather-dependent renewables, storage and more inter-dependence with neighbouring countries through electricity interconnection. There will be times when weather conditions will lead to very low output from renewable generation. These weather conditions may extend beyond GB affecting neighbouring countries too.

While consumers may shift their electricity usage away from such times, there may be limits on how much, or for how long, they can shift. We will need sufficient additional resources in the resource mix to deliver clean, reliable power at these times i.e. to maintain security of supply and ensure adequacy.

It is well known that technologies such as nuclear, carbon capture storage (CCS), hydrogen power generation and new long-duration storage are among the potential candidates. However, the trade-offs and critical paths are less well understood.

These options typically have long lead times to deliver; lead times that could be much longer than the timescales in the current Capacity Market arrangements, which is the main mechanism for delivering new capacity to ensure security of supply. These options may require investment in wider infrastructure to facilitate power generation; development of regulatory frameworks; and / or further research and development to help demonstrate their viability for full commercial-scale operation in GB.

There is a need to better understand the potential risks to adequacy in the 2030s, and the resources needed to provide reliable electricity supplies.

We have recognised this need by including a new sub-activity in our second RIIO-2 Business Plan (BP2) for 2023 – 2025. However, given the importance of this work, we wanted to start it earlier. We commissioned AFRY to undertake a long-term adequacy study to assess the risks to electricity security of supply in a fully decarbonised power system and the resources needed to ensure adequacy.

The study examines four different potential portfolios of resources – utilising different combinations of nuclear, CCS, hydrogen power generation and batteries.

Andy Dobbie
Modelling Senior Manager

The purpose is not to identify a definitive pathway or resource mix for GB; but rather to explore the range and mix of options that could ensure adequacy, the implications of them, and some of the trade-offs that might be required.

This is a first step towards understanding the scale of the challenge facing GB. It is intended to start the conversation on longer-term resource adequacy and does not provide a definitive view from the ESO. In keeping with this focus we have considered adequacy in isolation from related issues of operability.

We want to use this study to open engagement with expert stakeholders on the findings, modelling approach and assumptions that underpin the study. We warmly welcome feedback from our partners on this. Details on how to get involved can be found in these slides.

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[1] The British Energy Security Strategy stated that GB will have a fully decarbonised electricity system by 2035 (subject to security of supply).

Contents

Summary of the key findings

1

There is no trade off between adequacy and meeting Net Zero but we need to bring forward investment in clean, reliable technologies.

- Even at times of low output from weather-dependent renewable generation, it is possible to operate a fully decarbonised power system and meet customer demand.
- It will require large investment in clean, reliable technologies that are not weather-dependent. This could include: new nuclear, CCS, hydrogen power generation, new electricity storage or other technologies that can deliver energy on a scale of TWh or tens of TWh.
- There is uncertainty in relying upon new technologies. They typically have long lead times and some need to be proven at commercial-scale. Any barriers to delivering this capacity at scale by 2035 should be identified and addressed to reduce dependence on unabated gas.
- This study does not advocate for a preferred technology or combination of technologies in the future resource mix.

2

Understanding risks due to weather patterns will become increasingly important to ensure adequacy in a fully decarbonised system with high levels of weather-dependent generation.

- Weather patterns will be the dominant driver of stress periods in a fully decarbonised power system. This represents a change for the GB system, as tight periods have traditionally been driven by plant availability and high demand.
- New data sets will need to be developed to assess these risks appropriately.
- The most challenging situations are likely to be weather patterns extending across North-West Europe that result in prolonged periods of low wind during winter. Such weather patterns could lead to much longer periods of system tightness compared with those experienced today.
- While batteries play an important role, the nature of these weather patterns mean that adequacy cannot be ensured in a system that relies solely on batteries[1].
- There will be greater inter-dependence with neighbouring countries who may be experiencing similar weather conditions at the same time as us. How reliant we wish to be on imports from other countries is likely to be a GB energy policy decision.

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[1] This is shown in our study as we considered a case that relies on 6-hour batteries instead of any other new technologies. The case in our study showed a very high capacity (over 120 GW) but could not ensure adequacy, as the batteries could not provide sufficient energy to meet demand during prolonged adverse weather patterns (e.g. 120 GW of 6-hour batteries provides less than 1 TWh of energy).

Summary of the key findings

3

New modelling approaches and metrics will be required to assess risks to adequacy in a fully decarbonised power system.

- Great Britain currently has a statutory reliability standard of 3 hours loss of load expectation (LOLE)
- The GB system is expected to evolve from one where tight periods are relatively short to one where they could be much longer. Even though the duration of tight periods increases, the LOLE of the system remains broadly similar. This means that the inherent risk profile of the system is changing but the key metric is not.
- The modelling suggests that the GB system will be more susceptible to events that have a lower likelihood of occurring but will have a greater impact if they materialise. This is evident from longer-duration weather events becoming increasingly dominant in driving stress periods, for a similar LOLE value. This means that in many years, no tight periods on the GB system would be expected, but occasionally in other years, there could be prolonged tight periods that are more challenging.
- As the electricity system transitions to being fully decarbonised, industry and the government should work together to understand how to improve current approaches to the way that adequacy is measured. This could lead to new metrics that either support or replace existing ones such as LOLE.

4

It will become more important to consider adequacy in the context of developing the right markets, the right networks and future operability challenges to be confident that adequacy is ensured in a cost effective way.

- The economic viability of the resources was not considered in this study. The markets arrangements in which these resources operate in future could be very different to those that are in place today. The right market arrangements will need to be in place to bring forward investment in new resources that are needed to ensure adequacy. This could warrant further investigation through the ESO's work on Net Zero Market Reform[1] and / or the UK Government's Review of Electricity Market Arrangements (REMA)[2].
- The potential impact of network constraints has not been considered in this study. Future work will need to incorporate these considerations, given the current and likely future locations of renewable deployment.
- While the different resource mixes in our study had similar levels of adequacy, there could be significant differences in other related areas such as operability[3]. For example, there may be higher levels of excess energy and curtailment of renewables at other times of the year in a system where resources providing adequacy are less flexible.

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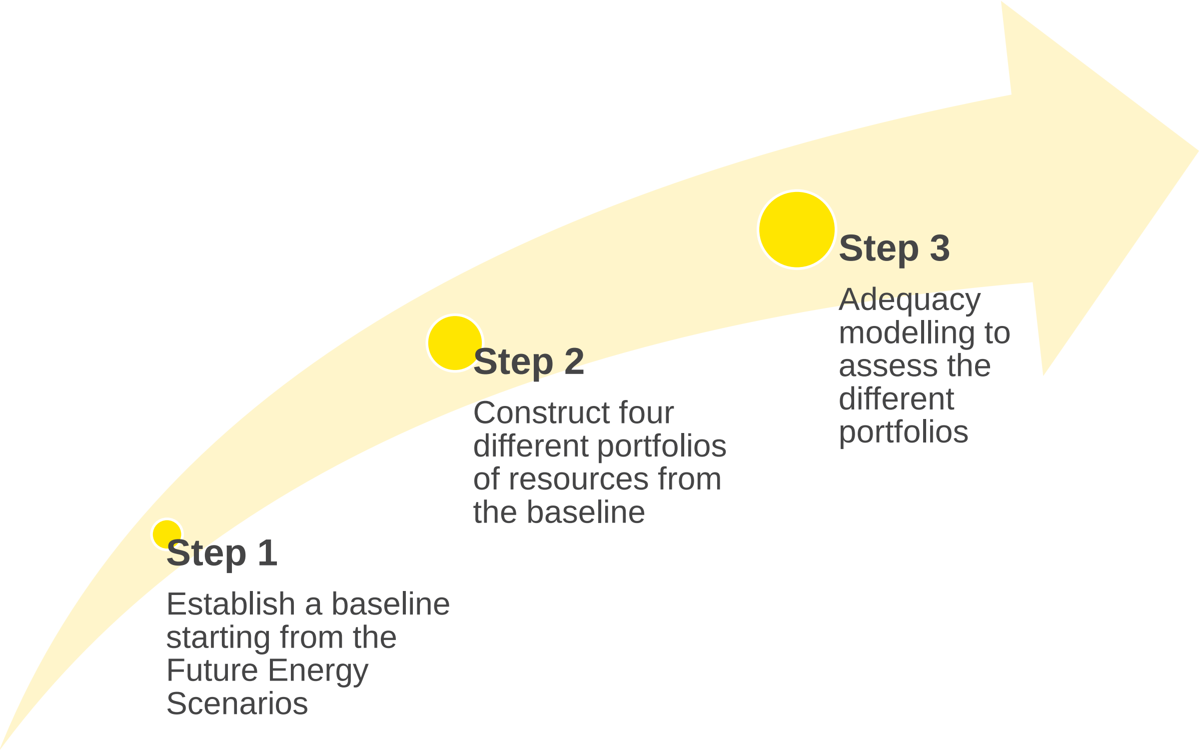
[1] https://www.nationalgrideso.com/future-energy/projects/net-zero-market-reform
[2] https://www.gov.uk/government/consultations/review-of-electricity-market-arrangements
[3] https://www.nationalgrideso.com/research-publications/system-operability-framework-sof

Our approach: overview

The aim of this study was to identify the potential risks to electricity security of supply in a fully decarbonised power system and the types of resources needed to ensure adequacy. The approach consisted of three key steps as set out in the figure below. The following slides set out further details for each step.



Step 1

Establish a baseline starting from the Future Energy Scenarios

Step 2

Construct four different portfolios of resources from the baseline

Step 3

Adequacy modelling to assess the different portfolios

Further details on our approach

This is a first step towards understanding the scale of the challenge facing GB. In keeping with this focus we have considered adequacy in isolation. Adequacy measures whether there are sufficient available resources to meet electricity demand throughout the year. In Great Britain, this has traditionally meant having sufficient margins when demand is highest in winter.

This study has not considered the impact of network constraints or future network developments; or future operability challenges that may occur at other times of the year when there are no adequacy concerns; or any changes to the current market arrangements. This is consistent with the approach widely adopted in other adequacy studies and significantly simplified the modelling for this first study. However, we recognise that in future studies, this may need reconsideration, one which will likely require us to develop new modelling capability.

We have used the Future Energy Scenarios (FES) as the starting point for our supply and demand assumptions[1]. The scenarios in the FES set out plausible pathways for energy supply and demand towards Net Zero. These pathways set out to reflect the credible range of uncertainty rather than serving as any predictions of the future. The FES is informed by an extensive stakeholder engagement process and so provides a robust foundation for this work. It also supports consistency with other ESO activities that use the FES. We used the assumptions in FES 2021 due to the timing of the study[2].

We have considered four different portfolios in this study. We recognise that this will not cover all potential technologies or combinations of technologies. We chose these ones to construct four distinct cases that would provide broader insight for this first study and serve as a starting point for further studies. The choice of technologies was based on those included in our FES. Neither our choices of technologies or the findings of this study advocate any preference for any particular technologies or combinations of technologies.

We have considered adequacy over 2025 – 2040. We have done this to assess both the transition to a fully decarbonised power system by 2035, as well as a period after which the system is expected to be fully decarbonised.

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[1] https://www.nationalgrideso.com/future-energy/future-energy-scenarios

[2] AFRY undertook this study in Jan – Jul 2022. This meant that we couldn't use the assumptions in FES 2022 as they hadn't yet been finalised.

Our approach
Step 1: establishing a baseline

The first step was to establish a baseline for the study starting from the FES. We used this baseline to assess the different portfolios of resources in a consistent manner.

Start from the FES

We used the Consumer Transformation scenario from FES 2021 as the starting point for our electricity supply and demand assumptions.

Set LOLE target

We adjusted the demand in the scenario to set a fixed, consistent target of around 1 hour LOLE per year across the 2025 – 2040 time horizon.

Remove capacity

We removed capacity to establish a baseline with a shortfall of capacity, from which we considered four different portfolios. Our approach led to us removing around 35 GW from the original scenario.

Baseline

Further details on our approach

We chose the Consumer Transformation scenario from FES 2021[1] as the starting point because it is one of the two scenarios that meets Net Zero on time. Of those two scenarios, we chose Consumer Transformation as it has both higher peak demand and higher levels of renewables, and so may provide greater insight on future adequacy challenges. We may consider the other scenarios in follow-up studies.

We chose to target a LOLE value of around 1 hour per year, which is lower than the current reliability standard of 3 hours per year, because it is more reflective of the LOLE values in recent winters[2].

We chose to retain the assumptions in the Consumer Transformation scenario for all renewable[3] capacities as these technologies are being brought forward via schemes such as Contracts for Difference. We also retained the assumptions for biomass CCS as the FES assumes it is needed to offset emissions from other sectors. High levels of demand side response (DSR) through consumer engagement are already assumed in this scenario, and so we chose to retain these too rather than vary them in Step 2.

We also retained the assumptions in the scenario for interconnection capacity as this helped limit the scope of any changes we made to GB only[4]. This is an area we may wish to explore in more detail in further studies.

We removed capacity to create a shortfall for us to consider our alternative portfolios. We removed any new-build nuclear, gas CCS and hydrogen power generation from the Consumer Transformation scenario that is not currently under construction. We also removed any new-build storage from the scenario that was assumed to come online from 2025 onwards.

We also chose to phase out all unabated gas by 2035 in our study. We did this to simplify the modelling as it ensured our alternative portfolios would be compliant with Net Zero emissions targets. We also considered it to reflect a worst-case scenario for adequacy as it would highlight greatest need for new capacity. The assumptions in our study do not indicate any intention to phase out all unabated gas by 2035.

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[1] Detailed assumptions for this scenario can be found in the FES 2021 Data Workbook.

[2] Recent LOLE values have typically been 0 – 0.2 hours per year. We needed to choose a non-zero value for the modelling approach to work, and rounding to the nearest whole number simplified the modelling considerably in this first study, particularly when it came to Step 2.

[3] As defined in the FES Data Workbook. This includes for example: biomass, hydro, marine, solar, waste and wind.

[4] While the GB assumptions were based on FES 2021, the timing of the study meant we could use assumptions from FES 2022 for countries in Europe. These can be found in the FES 2022 Data Workbook.

Our approach
Step 2: constructing different portfolios

The second step was to construct different portfolios of resources from our baseline. Having created a capacity shortfall in Step 1, we added capacity back in to create the four portfolios shown below. We stopped adding capacity back in when the LOLE value was back close to the target value of 1 hour per year. The technologies included in our portfolios were: 6-hour battery storage[1], nuclear[2], gas CCS[3] and hydrogen power generation[4].

Portfolio 1

Battery storage only

Portfolio 2

Gas CCS, hydrogen and battery storage

Portfolio 3

Nuclear, hydrogen and battery storage

Portfolio 4

Hydrogen and battery storage

Further details on our approach

We assumed all new battery storage had a duration of 6-hours. This represents a short extension to the 4-hour batteries currently coming through the capacity market, and so we considered portfolio 1 to be a case that relied on existing technologies.

We have not modelled hydrogen production in this study. In portfolios that have hydrogen power generation, we have assumed that hydrogen fuel supplies are always available. Hydrogen production is modelled in the FES[5], and we could seek to incorporate this more explicitly in our adequacy modelling in future.

We chose the levels of gas CCS and nuclear in portfolios 2 and 3 to be in the range of 15 – 20 GW, as these levels are broadly consistent with those in the FES. In portfolios 2 and 3, we also capped hydrogen power generation to around 5 GW. We did this to ensure there was greater distinction between these portfolios and portfolio 4.

We also assumed that there were no constraints on the amount of new-build capacity that could be delivered by 2033. We did this to simplify the modelling in this first study, and it is an assumption we could look to refine in future.

We recognise that our study has not considered all the potential new technology options. Instead we have tried to construct different portfolios that will provide broader insight here, and serve as a starting point for further studies. For example, we have not included all the different long-duration storage technologies. We reasoned that by including 6-hour batteries and hydrogen power generation in our study that this might cover the full potential range of storage duration. Hydrogen may be considered as the limiting case of seasonal storage, as it could potentially be produced at any time of the year and stored until needed. The duration of other storage technologies may be expected to fall somewhere in between this and batteries. However, we have not explicitly modelled this and this could be an area to explore in further studies.

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[1] E.g. Home | LDES Council which also includes information on other storage technologies not modelled in this study
[2] E.g. Nuclear energy: What you need to know - GOV.UK (www.gov.uk)
[3] E.g. UK carbon capture, usage and storage - GOV.UK (www.gov.uk)
[4] E.g. UK Hydrogen Strategy (publishing.service.gov.uk)
[5] E.g. see “How we do our modelling for FES 2022” Future Energy Scenarios 2022 | National Grid ESO

Our approach
Step 3: adequacy modelling

The third step was to carry out a comprehensive adequacy assessment for each of the portfolios. The adequacy assessment included 12 historic weather years. It also considered multiple plant outage patterns, modelled stochastically using Monte Carlo simulations. The adequacy assessment was used to calculate LOLE values and also “critically tight periods” – a metric used in this study to identify when demand was met but the system was very close to loss of load. In addition, we also modelled some illustrative events using full dispatch modelling. These were used to visualise how the different portfolios were ensuring adequacy.

Adequacy modelling

- Modelled spot years in the time horizon 2025 – 2040 each with twelve historic weather years
- Modelling approach was based on identifying tight periods first, and then undertaking detailed modelling of these periods with stochastic plant outages
- Calculated adequacy metrics such as LOLE, the number and distribution of tight periods

Visualisation of illustrative events

- Modelled spot years in the time horizon 2025 – 2040 each with five historic weather years
- Events based on weather from 1985 are illustrated in the AFRY report
- Each hour of the year modelled sequentially, with plant dispatched to meet demand at lowest cost
- Plant availability based on a single ‘average’ value from the adequacy modelling

Further details on our approach

We modelled the years 2025, 2028, 2030, 2033, 2035, 2038 and 2040 in our study. We chose these spot years to reduce the number of simulations without significant loss of insight.

The adequacy assessment used 12 historic weather years. We selected these weather years following an initial test of more than 30 historic years. The vast majority of these years showed no adequacy concerns (i.e. no loss of load). We selected the 12 years as the ones that were expected to be most challenging (e.g. cold spells, wind droughts). We believe it is reasonable to infer that our adequacy assessment is based on more than 30 historic weather years as the years we did not model in full (apart from our initial test) showed no adequacy concerns and would not contribute to the LOLE values.

The adequacy assessment did not model every hour of the year in full detail. Instead, we performed some initial simulations to identify the tight periods, which were then modelled in much greater detail. We believe this is appropriate because there are no adequacy concerns for the majority of the hours in the year. It also meant that we could focus our simulations on the periods of most interest and assess these much more thoroughly with different plant outage patterns.

We illustrated events based on weather from 1985 to visualise how the different portfolios of resources were ensuring adequacy. We chose 1985 as it included some of the events that are often cited by expert stakeholders as giving greatest cause for concern. These included a European-wide cold spell; a cold spell in GB; and a prolonged wind drought in winter. These events were also chosen to include potential corelation in adverse weather between GB and neighbouring countries. We modelled each hour sequentially of these events to make them easier to visualise.

Next steps and how you can get involved

December 2022

From January 2023

April – June 2023

First study published

- We will use this as our platform to open broader engagement with industry and to build on for further studies

Stakeholder engagement

- We intend to set-up round table discussions to invite debate on this study and help shape future studies
- We expect these to take place Jan – Mar and could be virtual / in-person
- Please can you contact Box.NetZeroAdequacy@nationalgrideso.com to register your interest in attending these sessions

Building our internal capability

- We have included this as a new activity in our second RIIO-2 Business Plan (BP2)
- While we commissioned AFRY to undertake this initial study, we remain committed to building our internal capability by March 2023 ready for BP2
- This includes building up a new team and deploying a new model for further studies

Planning for further studies

- We will use stakeholder feedback to shape future studies
- These could either be full studies and / or shorter follow-up studies that explore specific areas of interest
- We expect to share our developing plans with stakeholders in Q1 2023/24. We hope this will provide greater transparency and opportunity to co-create the modelling with us

Long term capacity adequacy assessment

A public report to National Grid ESO

JULY 2022

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EXECUTIVE SUMMARY - SCENE SETTING

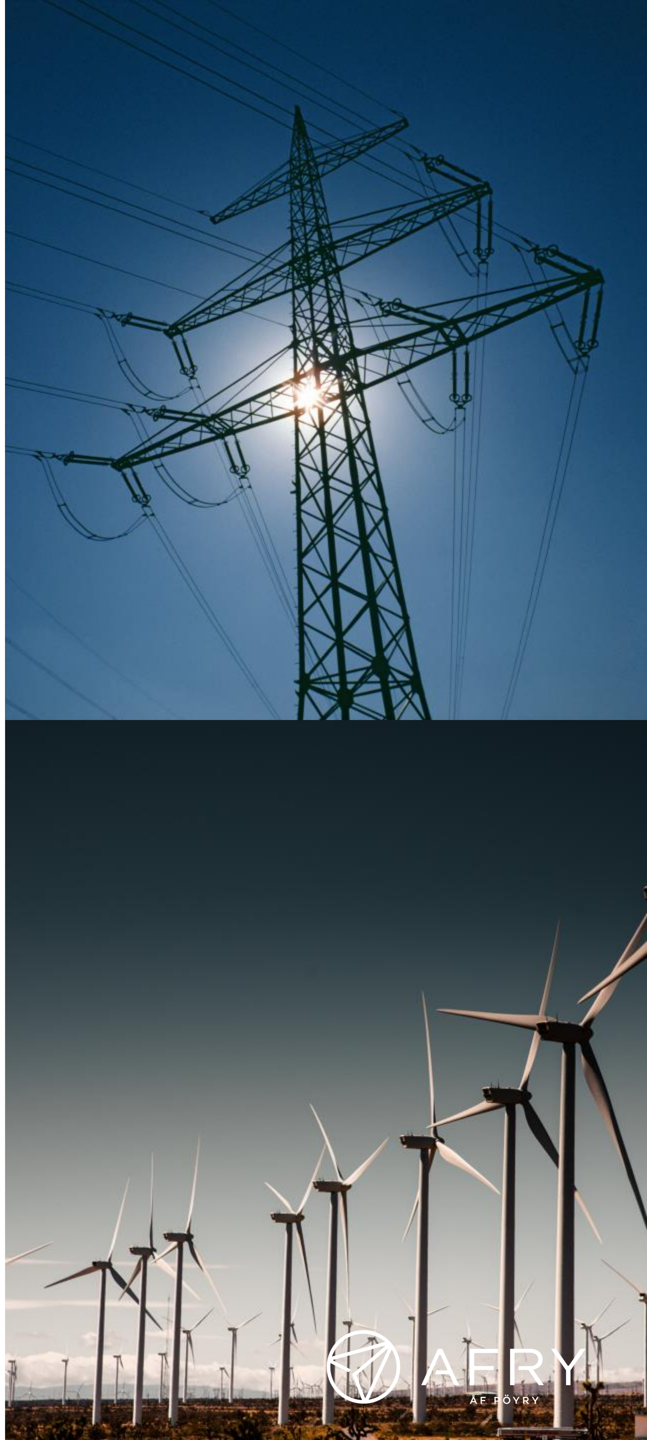
A radically different electricity system in the future may mean very different security of supply challenges

CONTEXT

- The transition to net zero will fundamentally alter the capacity mix on the electricity system, with much higher volumes of renewables, larger volumes of storage, as well as greater interconnection to surrounding countries. The generation mix required to meet net zero will present new challenges in ensuring system adequacy
- The Government announced in October 2021 that the power system will be carbon-free by 2035
- Technologies such as new nuclear, carbon capture storage and hydrogen generation could provide clean, reliable capacity. However, these technologies have long lead times to delivery and there is currently just one nuclear power station under construction
- National Grid ESO has asked AFRY to undertake a long-term adequacy study to assess the risks to security of supply in a fully decarbonised power system and the resources needed in the capacity mix to ensure adequacy

KEY QUESTIONS

1. What are the possible options for the capacity mix that could deliver system adequacy through the 2030s?
2. Are any of these options more favourable than the others from an adequacy perspective (e.g. what are the limitations of the different options)?



Key messages

1

New technologies enable the GB system to meet both net zero and adequacy targets

- Security of supply and net zero goals can be ensured using technologies such as hydrogen power plants, new nuclear or carbon capture and storage (CCS). However if **all** these technologies fail to come to fruition, the GB system will struggle to meet security of supply using limited duration batteries alone

2

Critical stress events move from typically a few hours in duration to multiple days in duration

- The GB system moves from one where critical stress events are a few hours in duration, and driven by high demand and plant failure, to one where critical stress events are due to weather events that last multiple days in duration.

3

Future system becomes more exposed to NW Europe-wide winter low wind events

- Winter periods with sustained cold weather and increased energy demand are the dominant periods of system stress. Increased interconnector capacity means the future system becomes much more exposed to NW Europe-wide periods of low generation (e.g., wind drought in winter), leading to much longer periods of system stress.

4

Interconnection means GB is more reliant on neighbours

- As the volumes of interconnection grows, the importance of understanding these flows during times of system stress becomes increasingly important: GB becomes reliant on (and a provider of) security from its neighbours

5

New metrics are required for future adequacy assessments

- The lengthening time of critical stress events and the increased interaction with NW Europe weather events may require new metrics to capture the changing nature of adequacy: in this study we have used the metric ‘Critically Tight Period’ – defined as periods when prices are at VOLL (Value of Loss Load)

Contents

Adequacy or reliability assessment aims to analyse the likelihood of an electricity system being unable to meet (some) customers' demand

WHAT IS ADEQUACY ASSESSMENT?

- Adequacy assessment is about running simulations of the future to understand the risk or the frequency of periods of loss of load
- Historically, the two main factors contributing to system adequacy were the reliability of plant (risk of outages) and the variability of demand (due to temperature and human behaviour)
- As a result, running a Monte Carlo simulation which 'draws' from statistical distributions of plant outages and demand can allow adequacy to be assessed
- However, given growing volumes of renewables and storage, both the weather and the intertemporal links between hours must be modelled
  - State of the art modelling techniques are required to capture these factors
- Adequacy assessment does not attempt to forecast the future, but rather identify potential shortcomings in the system which can be addressed proactively

HOW IS ADEQUACY CURRENTLY MEASURED?

LOLE (Loss of Load Expectation)

- The reliability of the GB electricity system is currently assessed using the LOLE reliability standard
- Represents the number of hours per year in which, over the long-term, it is expected statistically that supply will not meet demand. This approach is probabilistic: the actual amount will vary depending on
  - circumstances in a particular year, for example how cold the winter is
  - whether or not a large number of power plants fail to work on a given occasion
  - power output from wind generation
  - storage filling levels, interconnectors flows etc.
- However, it is important to note when interpreting this metric that a certain level of loss of load is not equivalent to the same amount of blackouts: in most cases, loss of load would be managed without significant impacts on consumers

Expected Energy Unserved (EEU)

- A related reliability metric is the EEU
- This is the amount of electricity demand - measured in MWh – that is expected not to be met by generation in a given year. This combines both the likelihood and the potential size of any shortfall. Just as in the case of LOLE, the EEU figure should not be taken to mean there will be that particular amount of blackouts, because we expect that in the vast majority of cases, this would be managed without significant impacts on consumers.

Alongside Loss of Load Expectation (LOLE) and EEU, we have also used '<u>Critically Tight Periods'</u> to denote periods when the system is 'on the edge'

WHAT IS THE DRAWBACK TO LOLE AND EEU?

- As described in the previous slide, Loss of Load Expectation is a standard metric to define system security. This counts the number of hours when load loss occurs ('load loss hours')
- In the 'old' world with little storage this metric worked well:
  - Hours when load loss occurred prices were at VOLL
  - When there was no load loss, prices were below VOLL
- However, in a system with lots of storage or flexible demand, suddenly all these lost load periods are linked together by energy storage. As a result, defining a load loss hour can be difficult or misleading
  - Frequently the electricity price is at VOLL, but there isn't actually load loss in that period. The load loss may be occurring in another country or in another period (either before or after).
  - With lots of storage the model or market may incur load loss in a different period to the one with prices at VOLL. This is either due to the optimal solution being for the model to group load loss in the same hours, or the problem being 'degenerate' (multiple answers with the same solution cost)
- Alternative metrics such as the loss of load probability (LOLP) –defined as the probability that load loss occurs in a given hour and country – suffer from similar shortcomings. The model could choose to have a high LOLP for a single hour or country. And any method of distributing it over a number of hours/countries can introduce biases.

WHAT IS A <u>'CRITICALLY TIGHT PERIOD'?</u>

- As a result, we have also used a new metric called 'Critically Tight Period'. This is similar to a load loss hour (prices are at VOLL) but there may not be load loss

- A <u>'Critically Tight Period'</u> is an hour when the electricity price is at Value of Lost Load (VOLL)
  - In our study, this means the electricity price is at £5000/MWh
- An alternative but identical definition could be:

  A 'Critically Tight Period' is a period when, if demand increases by one unit, load loss will happen in the system (either in another period or in another country)

- In our study, we find the load loss hours to often be very low (much lower than the number of hours when the price is at VOLL)
- As a result, we find that the 'Critically Tight Period' provides greater insight than the more conventional 'load loss hours' metric

MODELLING APPROACH (1): USE OF LOLE MODULE AND DISPATCH MODULE TOGETHER

In this study, we used the BID3 market model to simulate the GB and NW Europe power system with multiple weather patterns and random outages

BID3 market model using LOLE module

Simulation of the security of supply of the system

Inputs

- FES scenarios / generation mix accounting for any technology shortfalls
- Weather patterns
- Random generator/interconnector outage patterns

Method

- Focus on the hours or days when outages most likely
- Use random outages and weather patterns to simulate very large numbers of potential stress events

BID3 market model using Dispatch module

Simulation of the hourly economic dispatch of all plant on system

Inputs

- Generation mix and availability from LOLE module
- Fuel and carbon prices from FES assumptions
- Other data as for the LOLE module

Method

- Run all hours in the year sequentially, with plant, storage and interconnectors dispatched based on least cost optimisation
- Full economic dispatch of system accounts for plant technical characteristics (min stable generation, min on/off etc.) as well as all energy storage constraints and hydrogen system

Results

- Adequacy metrics including the loss of load expectation
- Weather and outages leading to load loss or critically tight hours

- Visualisation of the system operation at times of stress illustrating underlying reasons for load loss

BID3 has undergone a rigorous benchmarking by third parties. See https://afry.com/sites/default/files/2020-12/bid3_backcastreport_final_v100.pdf

MODELLING APPROACH (2): USE OF LOLE MODULE AND DISPATCH MODULE TOGETHER

We use the LOLE module to extract core adequacy metrics, and the Dispatch to illustrate and provide context around security of supply incidents

LOLE MODULE: KEY ADEQUACY METRICS

- Since the LOLE module focuses on groups of sequential hours when load loss is likely (for example low wind and high demand), it allows lots of outage simulations to be considered just for those periods
- Critically, it not only simulates outage cases for GB, but also for surrounding countries
  - This means it accurately reflects contributions from different interconnectors
- The LOLE module also simulates short-duration storage (energy constraints), so an 'hour group' of (say) 20 hours will have 2,4,6 and 8 hour batteries and storage accurately modelled
- However, since the LOLE module is sampling over blocks of sequential hours where load is likely it removes the rest of the year from consideration
  - This means you can't illustrate a whole year with a cold/still spell, as the model has only simulated the cold/still days and not the rest of the year
  - It also means the LOLE module cannot give whole-year results such as generation or interconnector flows
- Combining the LOLE module with an average-availability Dispatch run allows the best of both worlds

DISPATCH MODULE: ILLUSTRATIONS OF WHAT HAPPENS

- Since the Dispatch optimises all 8760 hours of the year, it does a complete (and detailed simulation) of a single year at a time
- As a result, it is very powerful for illustrating the periods when load loss is happening, what the reasons are for the load loss, and what technologies are producing
- We have run Dispatch simulations to give metrics such as annual generation, load factors, and also allowing illustrations of key periods

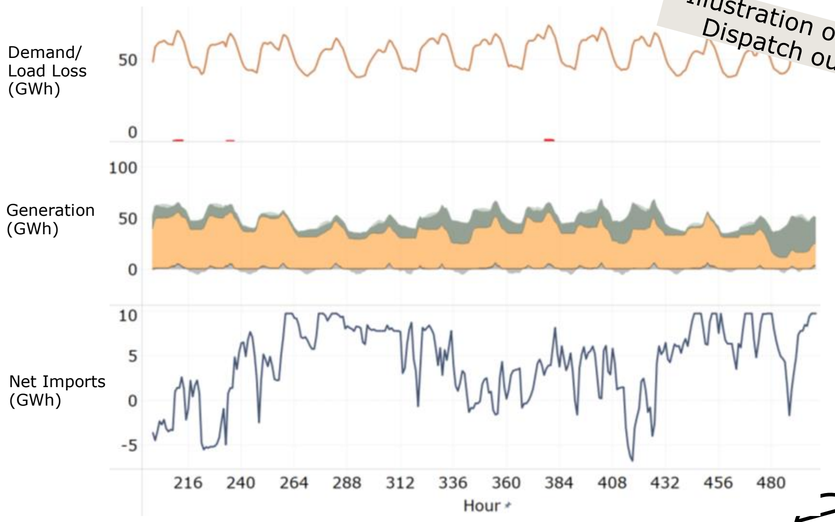


Illustration of typical Dispatch outputs

The study focused on three elements: examination of the resources required to provide system adequacy, a detailed assessment of load loss periods, and finally a visualisation of critical weather patterns

STUDY APPROACH

Assessment of the resources required for system reliability

Using the Consumer Transformation FES 2021 scenario as a basis, identified Net Zero technology mixes which can provide system reliability.

The 2025-2040 time horizon covering the transition to a fully decarbonised system is considered.

The reference has been artificially tightened using demand adjustments so that a consistent LOLE standard of ~1hour/year can be applied across all years and scenarios

Detailed analysis of load loss and tight hours

Comparisons of different capacity mixes

Run BID3 LOLE module for NW Europe (12 weather patterns selected from 1985-2018) to assess hours of lost load

Analysed resulting Critically Tight Periods

Run Dispatch module for 5 weather patterns to illustrate when tightest periods are and what is causing them

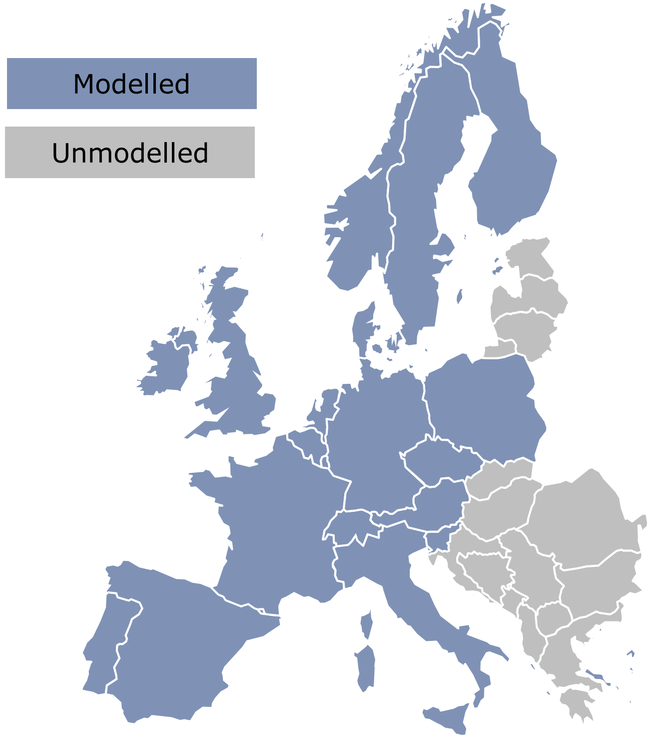
Visualise three critical weather patterns

Picked three critical weather patterns from 1985

Focussed on cold spells in GB and North-West Europe as well as an occasion of prolonged wind drought

Assessed impact on wholesale price, occurrences of load loss and the operation of generation and batteries

GEOGRAPHIC SCOPE

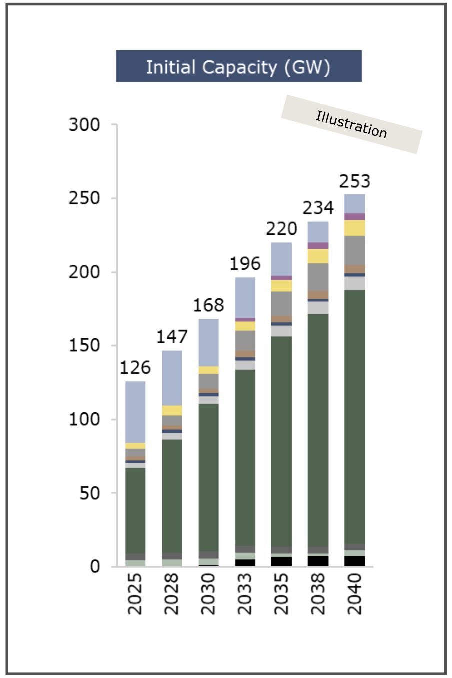


* CT = Consumer Transformation

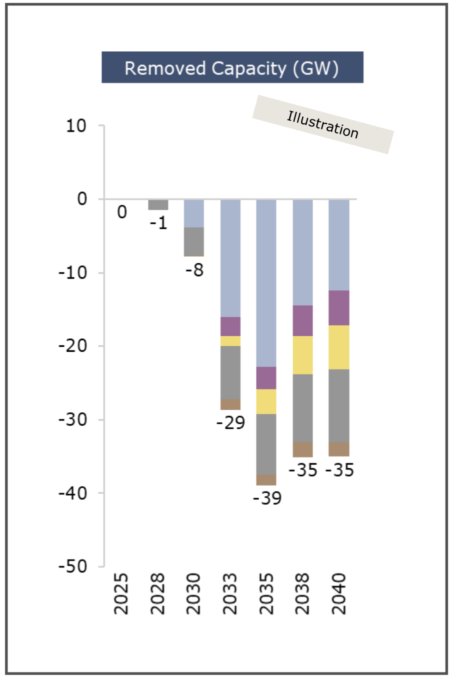
STUDY APPROACH – ASSESSING CAPACITY MIXES FOR SYSTEM RELIABILITY

Four technology mixes providing system reliability are considered by introducing a capacity shortfall in the reference scenario, then building back alternative technologies to meet the LOLE standard

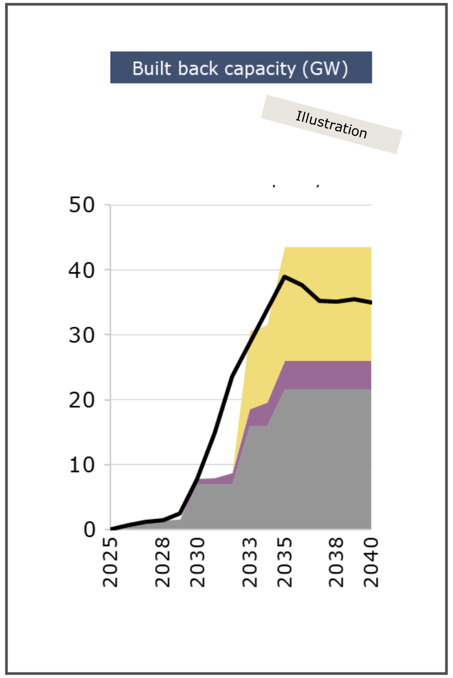
The FES Consumer Transformation pathway is used as a starting point


Initial Capacity (GW)

A shortfall in capacity is created by removing uncertain technologies


Removed Capacity (GW)

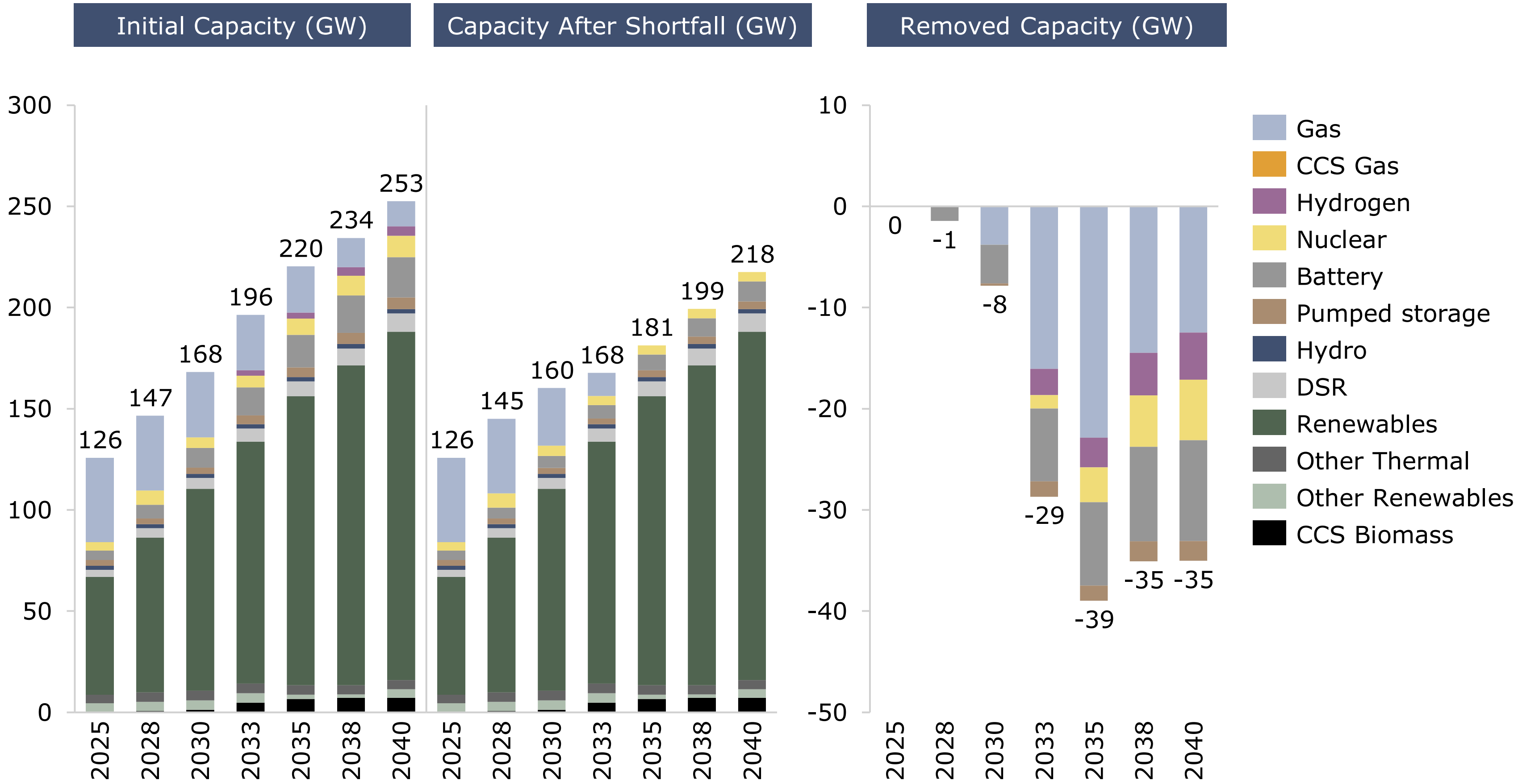
Based on technologies available, capacity is built back to meet LOLE


Built back capacity (GW)

The process to form capacity mixes which meet the reliability standard has a number of steps.

- **Perform reference scenario alignment.** The demand in the FES Consumer Transformation is adjusted to provide a consistent LOLE for scenario years 2025-2040.
- **Create capacity shortfall.** A shortfall is created from any new capacity that is not currently under construction for the technologies: nuclear, CCS gas, H2 and new storage assumed to come online after 2025. Assumptions on the future build of renewables, interconnectors, hydro and DSR, and existing thermal remain consistent with the reference scenario, apart from existing unabated gas that was restricted post 2030.
- **Build back technologies to meet same LOLE standard.** Four scenarios based on different combinations of batteries, nuclear, CCS gas and H2 are used to study the different capacity mixes which maintain the same reliability as the reference scenario

A shortfall was created by removing 35GW of capacity from the Consumer Transformation (reference) scenario

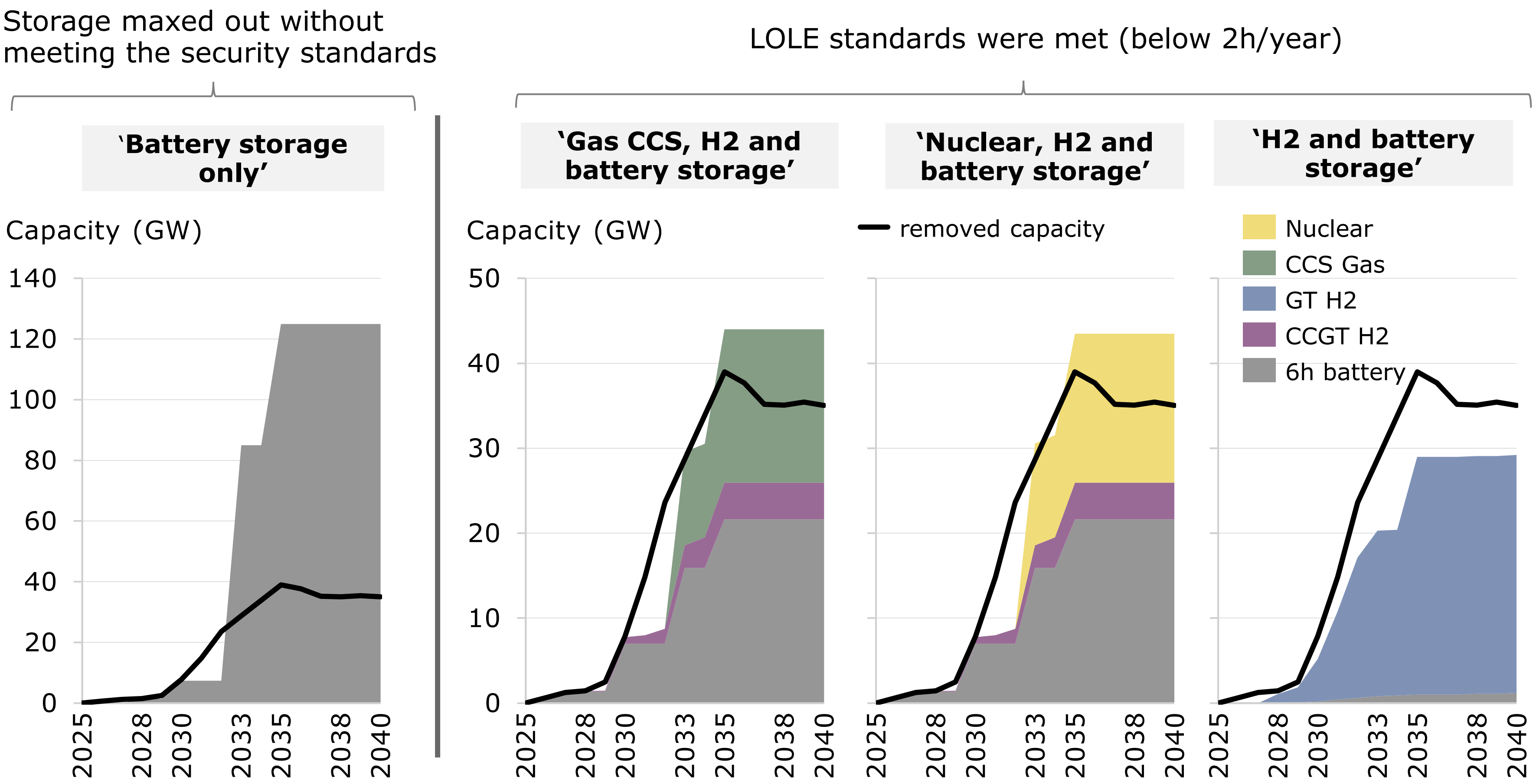


We removed all capacity that is yet to be committed or is under construction and restricted existing unabated gas capacity post 2030.

- **Unabated gas generators.** In a low-carbon scenario without negative emissions technologies, unabated gas CCGT usage would be restricted. This technology has been removed to maintain a low emissions system
- **H2 CCGTs.** Although H2 CCGTs are based on a mature technology, H2 may not be available in these timeframes
- **New nuclear.** Given a long history of delays and cancelled projects, there is caution on the delivery of new nuclear build
- **Battery**. Battery technology is rapidly evolving and there is uncertainty on their technical characteristics, costs and revenue streams
- **New pumped storage**. Any new pumped storage in GB would require a long planning process and construction time with the potential for delays

STUDY APPROACH – CREATING FOUR ALTERNATIVE CASES

Four new cases were created using different capacities and technologies built back, with the same LOLE standard as the original CT* scenario


Storage maxed out without meeting the security standards

LOLE standards were met (below 2h/year)

'Battery storage only'

'Gas CCS, H2 and battery storage'

'Nuclear, H2 and battery storage'

'H2 and battery storage'

- The 'Battery storage only' case only permitted batteries to be built. This case could not be returned back to the original LOLE standard even with a massive 120GW of batteries being built: without new nuclear/CCS or H2 there is not enough firm capacity available
- The other three cases could be returned back to the original LOLE security standard with a mix of technologies
- The 'H2 and battery storage' case builds mainly GT H2 plant. These are small units with very high capacity contribution. As a result, less overall capacity is needed in this case compared to the 'Gas CCS, H2 and battery storage' or 'Nuclear, H2 and battery storage' cases where the unit size is much larger due to high levels of storage (with low de-rating factor)
- Following the decommissioning of unabated gas in the early 2030s, 2035 proves to be the most challenging year. Beyond that point, the tightness in the system is mitigated by the rapid growth in demand side response. case

* The LOLE standard was the same as the Consumer Transformation (reference) scenario

Contents

KEY QUESTIONS

1. What are the possible options for the capacity mix that could deliver system adequacy through the 2030s?

OVERVIEW OF LOLE ACROSS CAPACITY MIX OPTIONS

A failure of some key low carbon technologies to deliver, such as H_2, new nuclear or CCS, does not imperil security of supply. However if **all** these technologies fail to come to fruition, the GB system will struggle to meet security of supply using battery technologies alone

Loss of load expectation (LOLE) of each scenario (hours)

Case	**2025**	**2028**	**2030**	**2033**	**2035**	**2038**	**2040**
'Consumer Transformation' (reference)	0.6	1.0	0.8	0.3	0.6	0.9	0.9
'Gas CCS, H2 and battery storage'	0.6	0.8	0.7	1.4	1.9	0.4	0.3
'Nuclear, H2 and battery storage'	0.6	0.8	0.7	0.7	2.0	0.5	0.4
'H2 and battery storage'	0.6	0.9	0.8	0.7	1.6	0.6	0.4
'Battery storage'	0.6	0.8	0.7	12.7	27.9	15.1	9.3

- The technologies available in 'Gas CCS, H2 and battery storage', 'Nuclear, H2 and battery storage' and 'H2 and battery storage' are able to restore the system to a reliability in line with requirement

- The build options available in the 'Battery storage only' case are not sufficient to meet the LOLE defined by the reference scenario (around 1 hour/year)
    - In this case we have built over 120GW of battery capacity, and the LOLE is still substantially greater than the target
- In this scenario, batteries with up to 6 hours duration of storage are not sufficient to compensate for the capacity removed from the 'Consumer Transformation' scenario

CAPACITY MIX OPTIONS

Similar LOLE security standards were met by different technology mixes in each case

Reference scenario

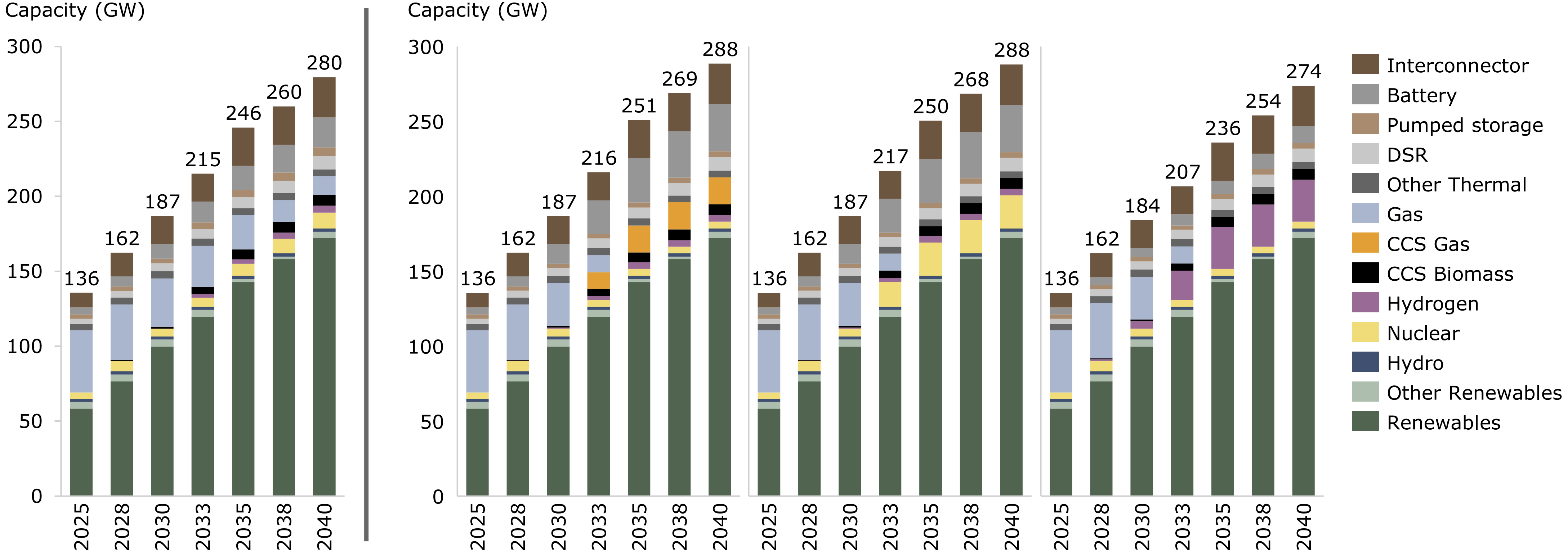
Investigated technology mix options

'Consumer Transformation'

'Gas CCS, H2 and battery storage'

Nuclear, H2 and battery storage'

'H2 and battery storage'



Note: 'Batteries only' scenario is not shown, as this scenario could not be made adequate (sufficiently secure) so is not a viable technology mix

The different cases have substantially different generation patterns

Reference scenario

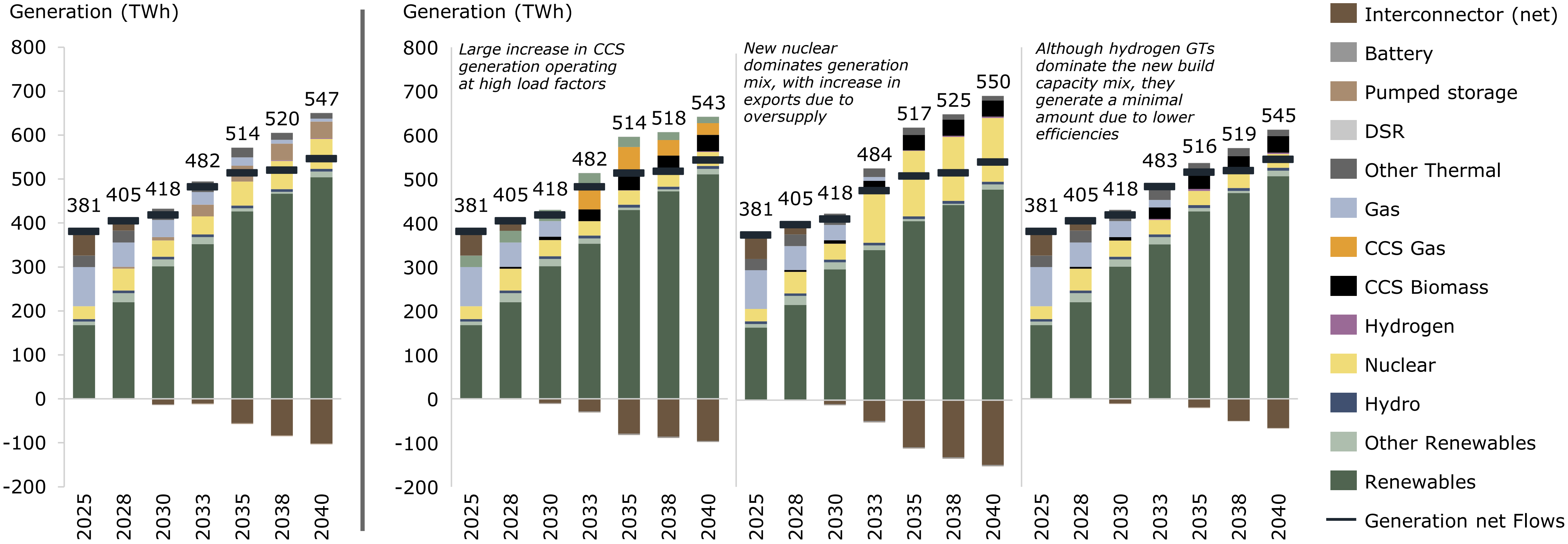
'Consumer Transformation'

Investigated technology mix options

'Gas CCS, H2 and battery storage'

Nuclear, H2 and battery storage'

'H2 and battery storage'



Large increase in CCS generation operating at high load factors

New nuclear dominates generation mix, with increase in exports due to oversupply

Although hydrogen GTs dominate the new build capacity mix, they generate a minimal amount due to lower efficiencies

Note: 'Battery storage only' scenario is not shown, as this scenario could not be made adequate (sufficiently secure) so is not a viable technology mix

KEY QUESTIONS

2. Are any of these options more favourable than the others from an adequacy perspective (e.g. what are the limitations of the different options)?

LENGTH OF CRITICAL STRESS EVENTS

The duration of the critical stress events in the GB system increases over time due to additional wind, flexible demand and storage, especially in scenarios using batteries to ensure security of supply

	Year	Distribution of length of critically tight periods (hours)										Mean length of critically tight periods (hours)
		<3	3-4	5-7	8-15	16-25	26-50	51-75	76-100	101-150	>150	
'Consumer Transformation' (reference)	**2025**	15	31	6	8	0	0	0	0	0	0	5
	2028	10	28	2	10	2	0	0	0	0	0	6
	2030	5	24	3	9	0	1	0	0	0	0	6
	2033	1	8	2	3	0	5	1	0	0	0	17
	2035	1	5	1	2	1	6	1	0	0	0	21
	2038	0	0	0	2	0	5	4	0	0	0	45
	2040	0	0	0	2	0	5	4	0	0	0	44
'Gas CCS, H2 and battery storage'	**2025**	15	31	6	8	0	0	0	0	0	0	5
	2028	13	25	1	9	2	0	0	0	0	0	5
	2030	11	12	2	2	0	4	1	0	0	0	10
	2033	0	1	0	0	4	3	8	1	0	0	42
	2035	0	0	0	0	2	3	4	3	1	0	58
	2038	0	0	0	2	0	3	4	2	0	0	50
	2040	0	0	0	1	0	4	2	0	0	0	43
'Nuclear, H2 and battery storage'	**2025**	15	31	6	8	0	0	0	0	0	0	5
	2028	13	25	1	9	2	0	0	0	0	0	5
	2030	11	12	2	2	0	4	1	0	0	0	10
	2033	0	0	0	1	3	4	8	1	0	0	44
	2035	0	0	0	0	2	4	4	3	1	0	57
	2038	0	0	0	2	0	3	4	2	0	0	51
	2040	0	0	0	1	0	5	3	1	0	0	52
'H2 and battery storage'	**2025**	15	31	6	8	0	0	0	0	0	0	5
	2028	12	28	0	11	0	0	0	0	0	0	5
	2030	9	25	2	10	2	0	0	0	0	0	6
	2033	1	11	1	5	0	7	1	0	0	0	17
	2035	1	6	1	1	1	5	4	0	0	0	24
	2038	0	0	0	2	0	4	5	0	0	0	43
	2040	0	0	0	2	0	5	3	0	0	0	41

- Future years see a trend to increase the mean length of critically tight hours from around 5 hours in 2025 to 45 (i.e. two days) by 2038
- This is driven by an increase in technologies with intertemporal characteristics
- Wind droughts can lead to reduced generation for sustained periods. While increased storage technologies (including flexible demand) leads to greater shifting of energy between hours (and days)
- As a result, it is very difficult for a stress event to effect a single hour in isolation, as there is always sufficient capacity available
- However, for longer periods of stress, coinciding with low wind, the energy storage constraints become critical, linking multiple hours together and leading to longer Critically Tight Periods
- 'Nuclear, H2 and battery storage' and 'Gas CCS, H2 and battery storage' see the greatest increase due to the greater penetration of batteries

LENGTH OF LOAD LOSS PERIODS

Hours with unserved energy (lost load) in the GB system show a similar relationship to Critically Tight Periods, although the relationship is less dramatic

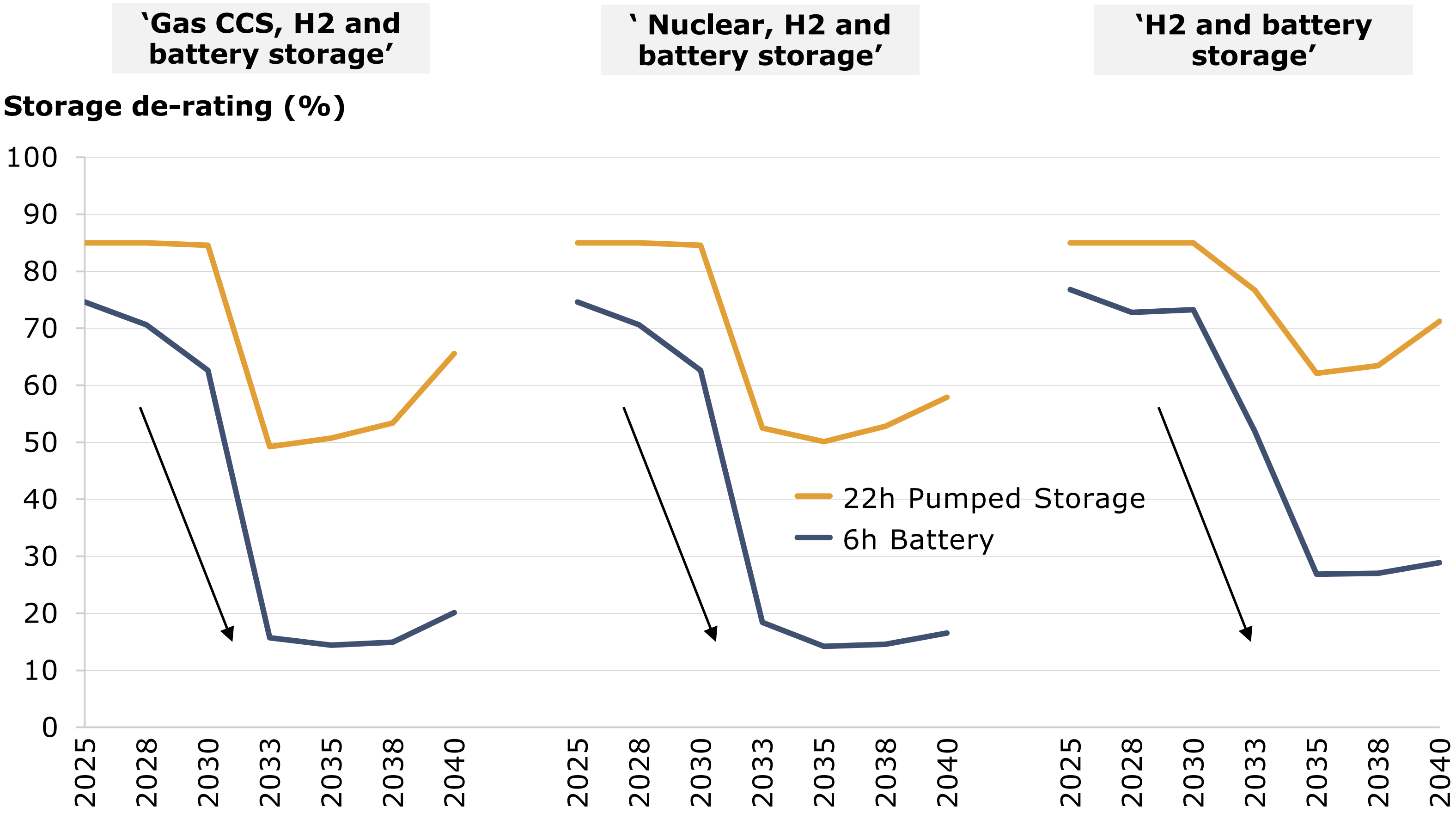
	Year	Distribution of length of hours with unserved energy (hours)										Mean length of load los periods (hours)
		<2	2-3	4-5	6-9	10-14	15-22	23-30	31-40	41-50	>50	
'Consumer Transformation' (reference)	**2025**	3	26	19	0	3	0	0	0	0	0	4
	2028	2	24	9	1	5	0	0	0	0	0	4
	2030	3	20	8	4	2	0	0	0	0	0	4
	2033	8	12	5	6	2	0	0	0	0	0	4
	2035	3	8	4	5	6	1	0	0	0	0	6
	2038	7	12	5	5	4	2	0	1	0	0	6
	2040	2	16	8	2	3	2	0	1	0	0	6
'Gas CCS, H2 and battery storage'	**2025**	3	26	19	0	3	0	0	0	0	0	4
	2028	1	27	6	3	3	0	0	0	0	0	4
	2030	3	13	2	2	5	0	0	0	0	0	5
	2033	7	14	11	14	1	3	4	0	1	0	7
	2035	6	10	9	10	2	6	3	0	1	0	8
	2038	5	12	8	7	4	4	0	0	1	0	7
	2040	2	8	2	4	2	1	1	0	0	0	6
'Nuclear, H2 and battery storage'	**2025**	3	26	19	0	3	0	0	0	0	0	4
	2028	1	27	6	3	3	0	0	0	0	0	4
	2030	3	13	2	2	5	0	0	0	0	0	5
	2033	8	18	12	11	2	5	4	0	0	0	7
	2035	7	11	7	14	5	5	3	0	2	0	9
	2038	7	8	7	8	4	5	1	0	1	0	8
	2040	5	10	9	5	2	4	1	0	1	0	7
'H2 and battery storage'	**2025**	3	26	19	0	3	0	0	0	0	0	4
	2028	6	27	6	4	2	0	0	0	0	0	4
	2030	5	20	8	5	2	0	0	0	0	0	4
	2033	2	18	6	10	2	2	0	0	0	0	5
	2035	9	12	3	8	6	2	0	0	0	0	6
	2038	1	11	5	5	3	3	0	0	0	0	6
	2040	3	3	1	3	3	2	0	0	0	0	7

- There are many more critically tight hours (where prices are at VOLL*) than hours with unserved energy
- As a result, the relationship is less dramatic than with critically tight hours, although the average length of periods with unserved energy increases 50% from 4 to 6 hours
- By 2038, due to the large amounts of wind, storage and DSR, sees periods with continuous unserved energy lasting for 31-40 hours
- The mean length of load loss hours can be used as a proxy for the LOLE and this has similar levels across years and scenarios
- Later years see a smaller number of periods with energy not supplied, though with an increase in mean length

* VOLL = Value of Lost Load, or the maximum price in the system

PERFORMANCE OF STORAGE

Storage duration will need to be tens of hours or days in duration to assist with critical stress events; tight hours can no longer be met by storage with a few hours duration



Storage de-rating factor
The contribution of storage capacity to alleviate load loss during Critically Tight Periods

- As shown in the previous slide, the future system will have much more infrequent periods with much longer duration of load loss
- As a result, longer duration batteries are more useful to the system. This is manifested in the storage de-rating factor.
- A battery with a higher de-rating factor is worth more (in security of supply terms) than a battery with a much lower de-rating
- As a result, a battery with 6 hours of storage is worth about 75% of firm capacity in 2025, but this rapidly falls to 15% by 2033. Storage with 22h is worth slightly more in 2025 (85%) and falls off much more slowly, being worth around 50% by 2033

TWO-WEEK SYSTEM SNAPSHOTS

Future system becomes more exposed to NW Europe-wide winter low wind events: we have illustrated this with three different weather events

Europe-wide cold spell

10 Jan – 19 Jan 1985

> *“A very cold period with substantial snowfall and a mix of low and high wind speed periods, with load loss result from both cold temperatures and wind speeds”*

We chose January 1985 as it has a mix of different extreme weather.

In particular, 16 Jan was one of the coldest days of the century in the south of the UK and 20cm of snow across much of the south

Cold spell

14 Nov – 1 Dec 1985

> *“A short period of unusually very cold weather and snowfall, however wind speeds remained moderate throughout, so adequacy issues are caused by temperature”*

We have chosen mid-late November 1985 as it was marked by two periods of unusually cold weather. 29 Nov was particularly cold with average temperatures well below zero across the UK, with − 12degC in West England and −14degC across central Scotland. Wind speeds were, however, moderate throughout

Wind Drought

19 Feb – 3 Mar 1985

> *“A very long period of low wind speeds due to high pressure areas over NW Europe causes system issues due to storage not being able to refill”*

We have chosen late Feb 1985 was an unusually long period of very low wind speeds, right across NW Europe, with a persistent high pressure anti-cyclone sitting over the North Sea

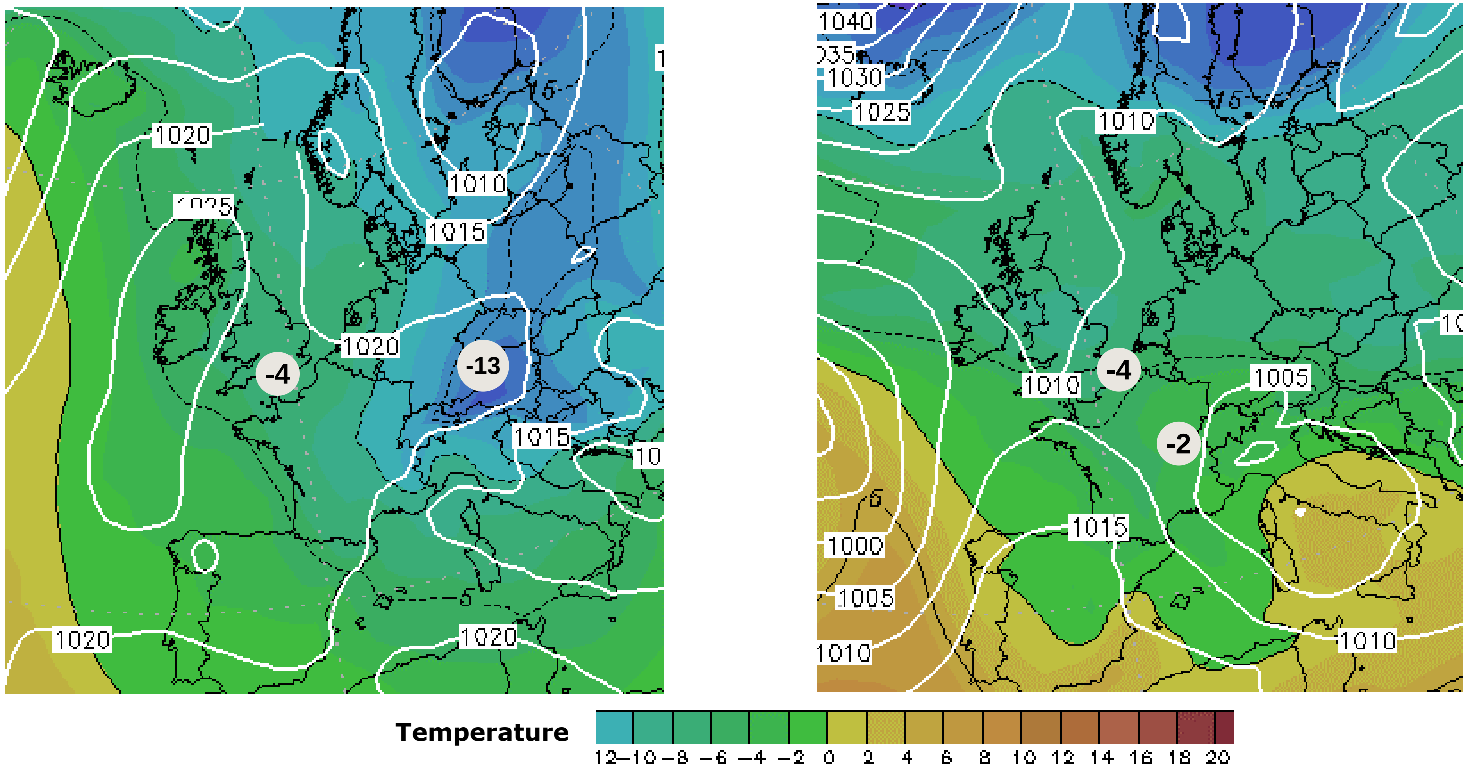
Note: We have focused our snapshots on one historical weather pattern: 1985, as it contains many of the interesting and relevant weather patterns. The analysis looked at weather patterns from 1985-2018

TWO-WEEK SYSTEM SNAPSHOTS: EUROPE-WIDE COLD SPELL

A very cold period with substantial snowfall and a mix of low and high wind speed periods

10 Jan 1985

19 Jan 1985



Source: www.wetterzentrale.de

Europe-wide cold spell

8 Jan – 22 Jan 1985

January 1985 was very cold with frequent snowfall in the first three weeks of the month. Notable was heavy snow in Kent on at the beginning of January – up to 25cm and temperatures reaching a daytime high of only -4degC.

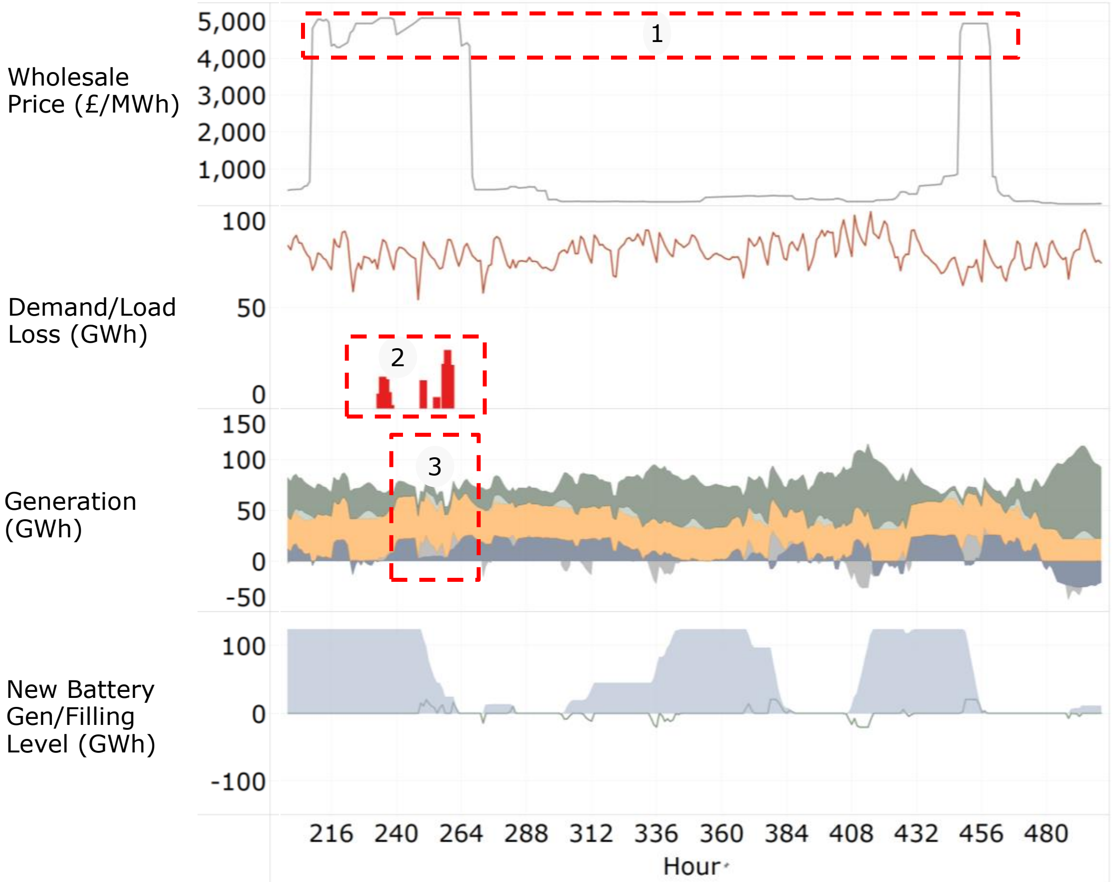
The 16 Jan was one of the coldest days of the century parts of the south of the UK and 20cm of snow across much of the south. Wind in S England was minimal, but a band of stronger breezes of 20-30knots stretched from Scotland, across the North Sea through Denmark and Germany, giving plenty of wind generation. Temperatures across NW Europe were not as low as a week earlier with the UK experiencing some of the coldest temperatures in Europe

SUPPORTING MATERIAL

How to read the slide

- Demand
- Load loss
- Wind Gen
- RES excl. Wind Gen
- Thermal Gen
- Storage Gen
- Net Imports
- New Build Battery Gen
- New Battery Filling Level

Illustrative diagram



Wholesale price
Box 1. Electricity price at VOLL (close to £5000/MWh) indicates ‘Critically Tight Periods’

Demand level and load loss periods
The demand includes the end user electricity demand, the role of flexible demand and/or battery operation. Increases and the change in nature of the demand is visible

Box 2. Blocks of load loss indicate hours with unserved energy

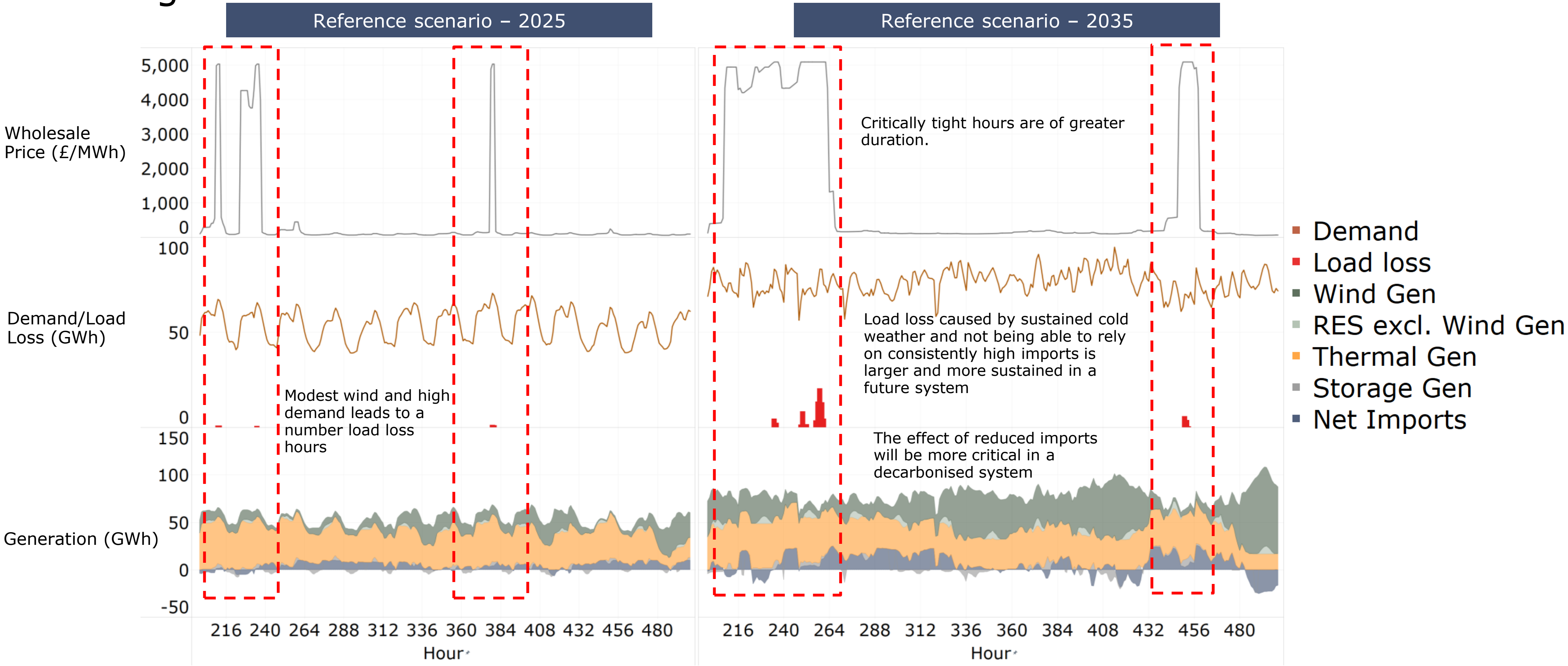
Generation mix and net imports
Box 3. Periods with low wind and imports can be identified in the GB system

Performance of the new build battery with 6 hours of storage
Visible is the system storage levels of the batteries (shaded area) and the net generation of the battery (line)

Note(s): Weather pattern presented is 1985 for mid-January; Thermal generation includes demand side response

EUROPE-WIDE COLD SPELL: REFERENCE CASE

The ‘Consumer Transformation (reference)’ scenario in 2035 is more exposed to Europe-wide cold spells; these can lead to load loss with greater duration and magnitude



Modest wind and high demand leads to a number load loss hours

Critically tight hours are of greater duration.

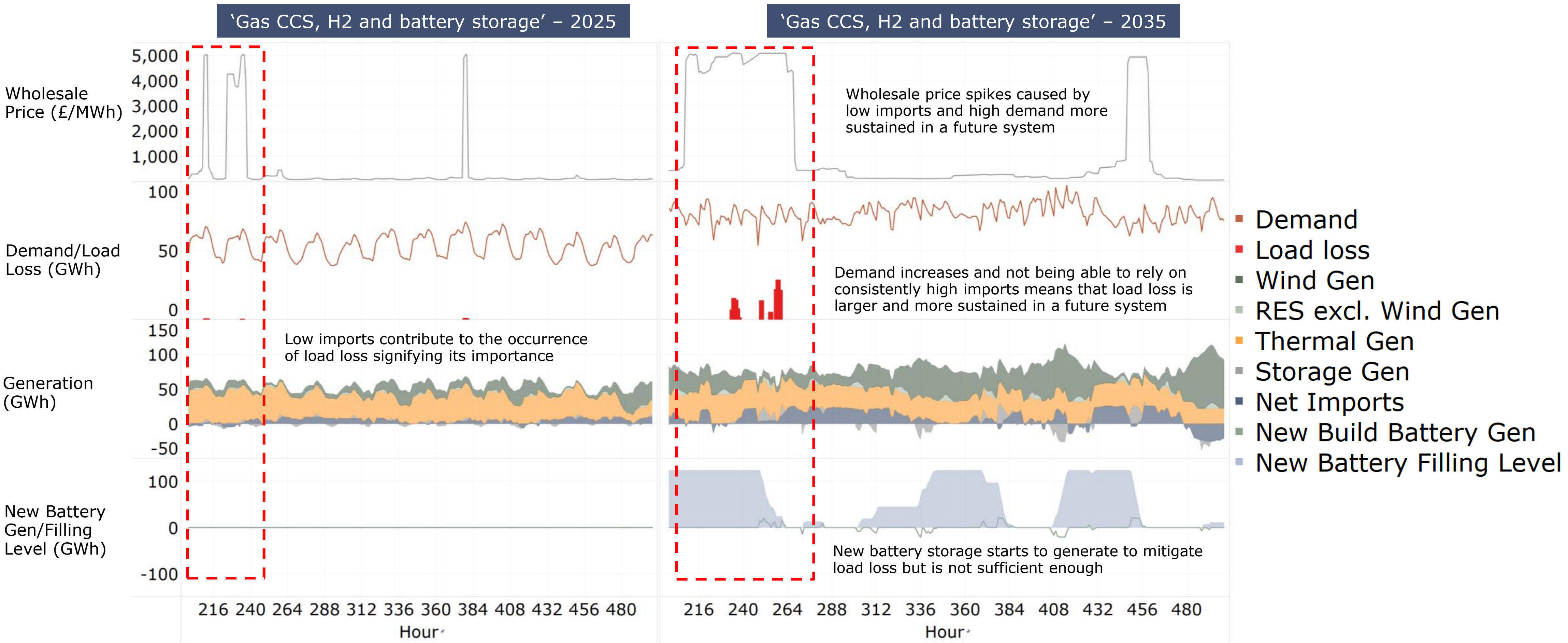
Load loss caused by sustained cold weather and not being able to rely on consistently high imports is larger and more sustained in a future system

The effect of reduced imports will be more critical in a decarbonised system

Note(s): Weather pattern presented is 1985 for mid-January; Thermal generation includes demand side response

EUROPE-WIDE COLD SPELL: ‘GAS CCS, H2 AND BATTERY STORAGE’ CASE

With a decarbonised system by 2035, the effect of demand spikes coupled with low wind and imports, will cause a larger, sustained amount of load loss



Low imports contribute to the occurrence of load loss signifying its importance

Wholesale price spikes caused by low imports and high demand more sustained in a future system

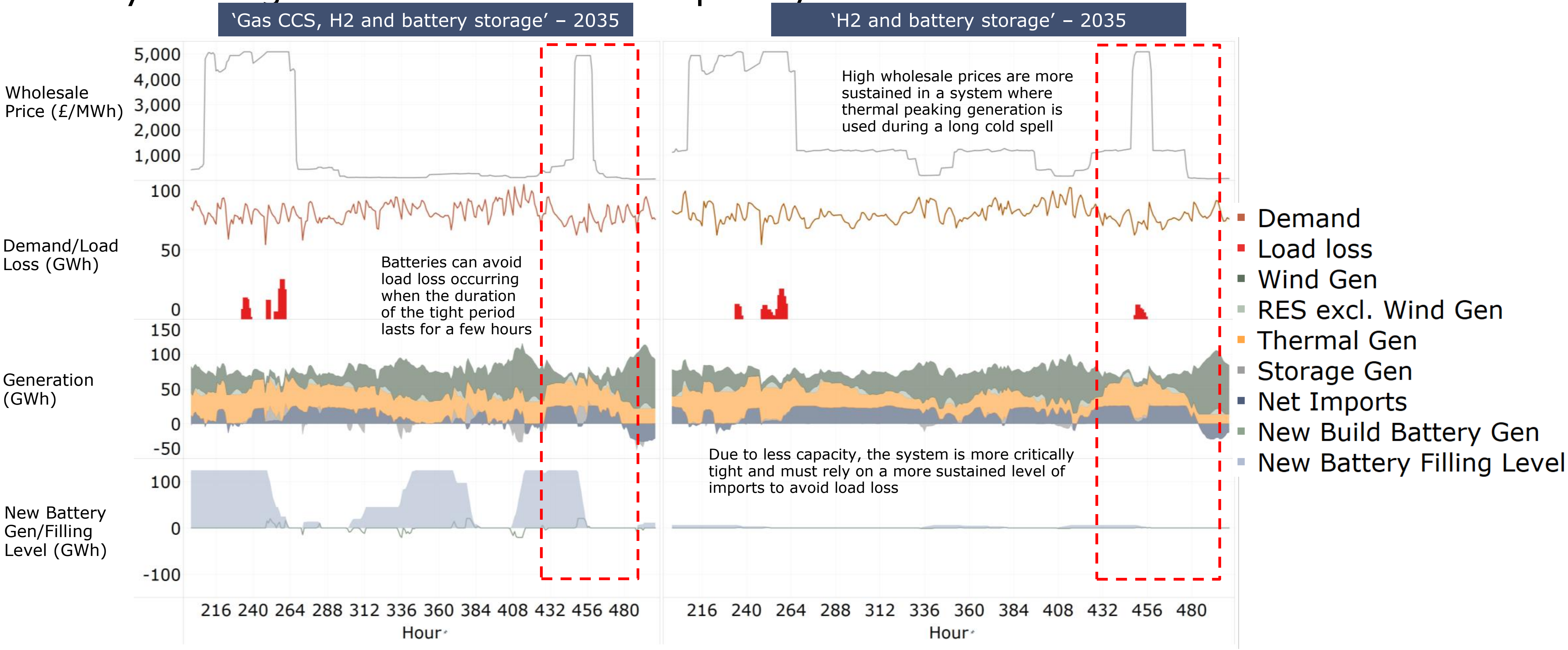
Demand increases and not being able to rely on consistently high imports means that load loss is larger and more sustained in a future system

New battery storage starts to generate to mitigate load loss but is not sufficient enough

Note(s): Weather pattern presented is 1985 for mid-January; Thermal generation includes demand side response

EUROPE-WIDE COLD SPELL: COMPARISON OF ‘GAS CCS, H2 AND BATTERY STORAGE’ AND ‘H2 AND BATTERY STORAGE’ CASES

The storage available in the ‘Gas CCS, H2 and battery storage’ scenario can meet demand when the shortfall in generation lasts for a few hours; ‘H2 and battery storage’ has less overall capacity and sees load loss at these times


‘Gas CCS, H2 and battery storage’ – 2035

‘H2 and battery storage’ – 2035

Batteries can avoid load loss occurring when the duration of the tight period lasts for a few hours

High wholesale prices are more sustained in a system where thermal peaking generation is used during a long cold spell

Due to less capacity, the system is more critically tight and must rely on a more sustained level of imports to avoid load loss

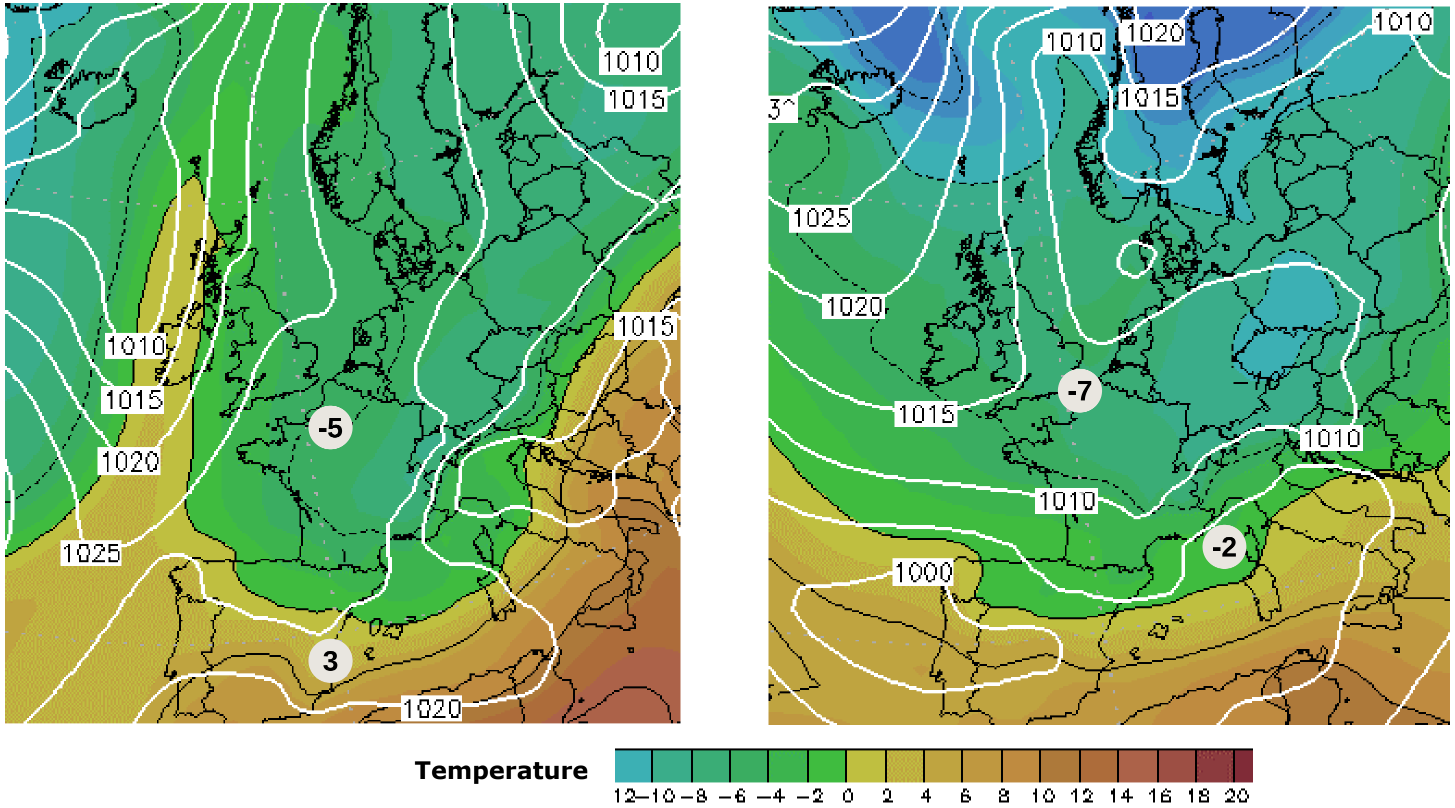
Note(s): Weather pattern presented is 1985 for mid-January; Thermal generation includes demand side response

TWO-WEEK SYSTEM SNAPSHOTS: COLD SPELL

A short period of very cold weather and snowfall, however wind speeds remained reasonable

14 Nov 1985

26 Nov 1985



Source: www.wetterzentrale.de

Cold spell

13 Nov – 27 Nov 1985

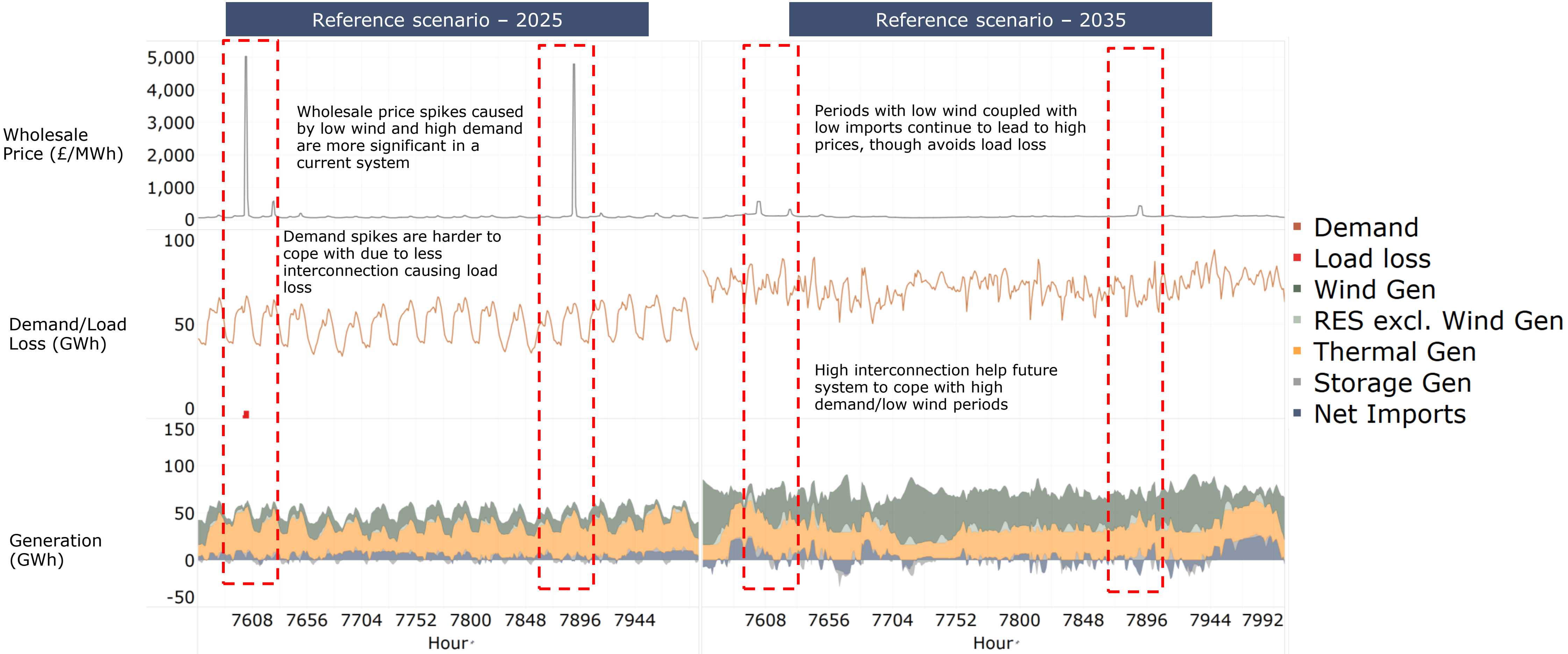
The winter of 1985-86 contained two periods of notably cold weather. We have illustrated the second half of November, which was the coldest November on record since 1922

The 14 Nov began with a severe frost in parts of SE England with overnight temperatures of -8degC and snow. A period of relative warmth followed, but the latter part of the month was marked by a high pressure area over Greenland, and resulting arctic temperatures. However wind speeds remained around 15-25knots.

27 Nov was particularly cold with average temperatures well below zero across the UK, with -12degC in West England and -14degC across central Scotland. Wind speeds in GB were mostly below 5knots, but across France, Germany and Poland they were up to 30knots.

COLD SPELL: REFERENCE CASE

Further interconnection and storage mean that the future ‘Consumer Transformation’ (reference) is more resilient to short cold spells in GB



Reference scenario – 2025

Reference scenario – 2035

Wholesale price spikes caused by low wind and high demand are more significant in a current system

Demand spikes are harder to cope with due to less interconnection causing load loss

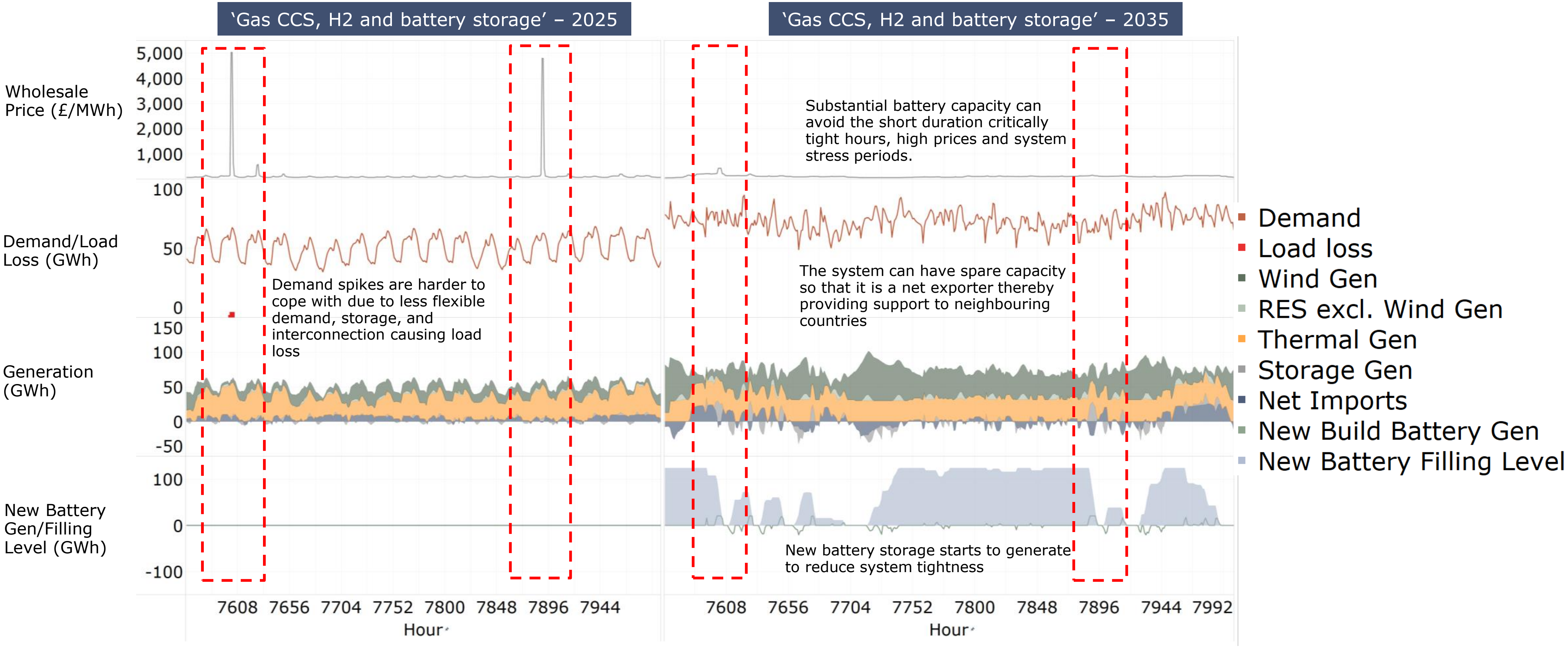
Periods with low wind coupled with low imports continue to lead to high prices, though avoids load loss

High interconnection help future system to cope with high demand/low wind periods

Note(s): Weather pattern presented is 1985 for the cold spell of mid-November; Thermal generation includes demand side response

COLD SPELL: ‘GAS CCS, H2 AND BATTERY STORAGE’ CASE

Flexible demand, storage, and interconnection allow future system to cope with critical weather patterns that result in load loss in the current system



Demand spikes are harder to cope with due to less flexible demand, storage, and interconnection causing load loss

Substantial battery capacity can avoid the short duration critically tight hours, high prices and system stress periods.

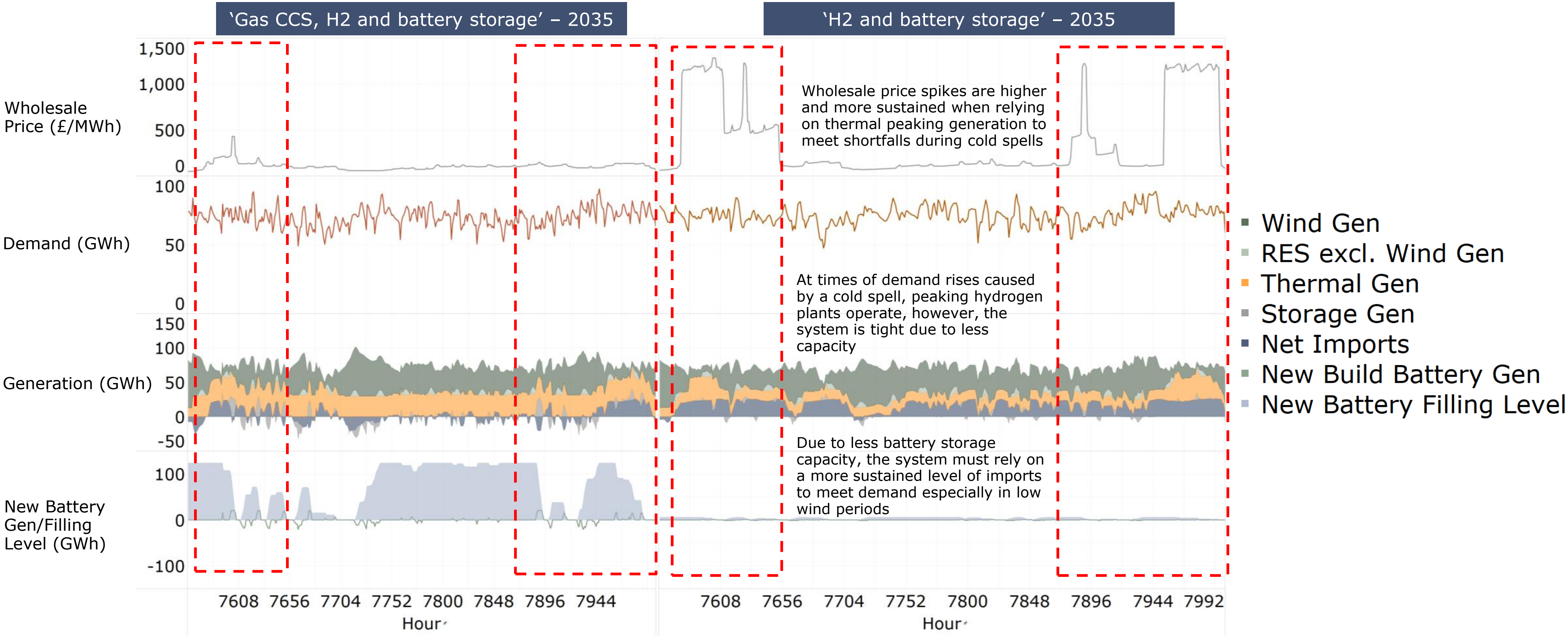
The system can have spare capacity so that it is a net exporter thereby providing support to neighbouring countries

New battery storage starts to generate to reduce system tightness

Note(s): Weather pattern presented is 1985 for the cold spell of mid-November; Thermal generation includes demand side response

COLD SPELL: COMPARISON OF ‘GAS CCS, H2 AND BATTERY STORAGE’ AND ‘H2 AND BATTERY STORAGE’ CASES

The effect of a cold spell resulting in high demand will be more critical to a system with less storage which will rely mostly on imports



Wholesale price spikes are higher and more sustained when relying on thermal peaking generation to meet shortfalls during cold spells

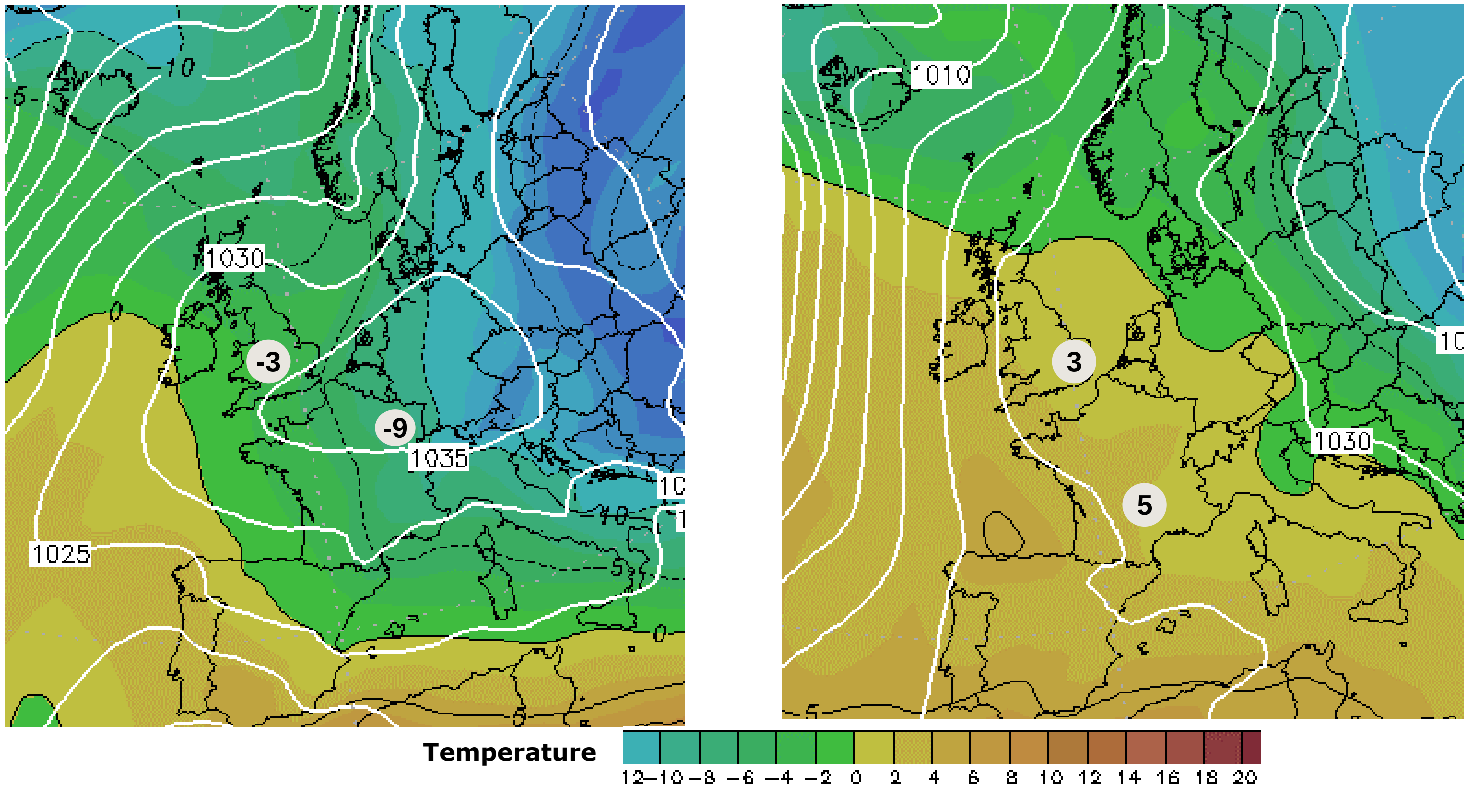
At times of demand rises caused by a cold spell, peaking hydrogen plants operate, however, the system is tight due to less capacity

Due to less battery storage capacity, the system must rely on a more sustained level of imports to meet demand especially in low wind periods

Note(s): Weather pattern presented is 1985 for the cold spell of mid-November; Thermal generation includes demand side response

TWO-WEEK SYSTEM SNAPSHOTS: WIND DROUGHT

A very long period of low wind speeds due to high pressure areas over NW Europe causes system issues due to storage not being able to refill



20 Feb 1985

27 Feb 1985

Source: www.wetterzentrale.de

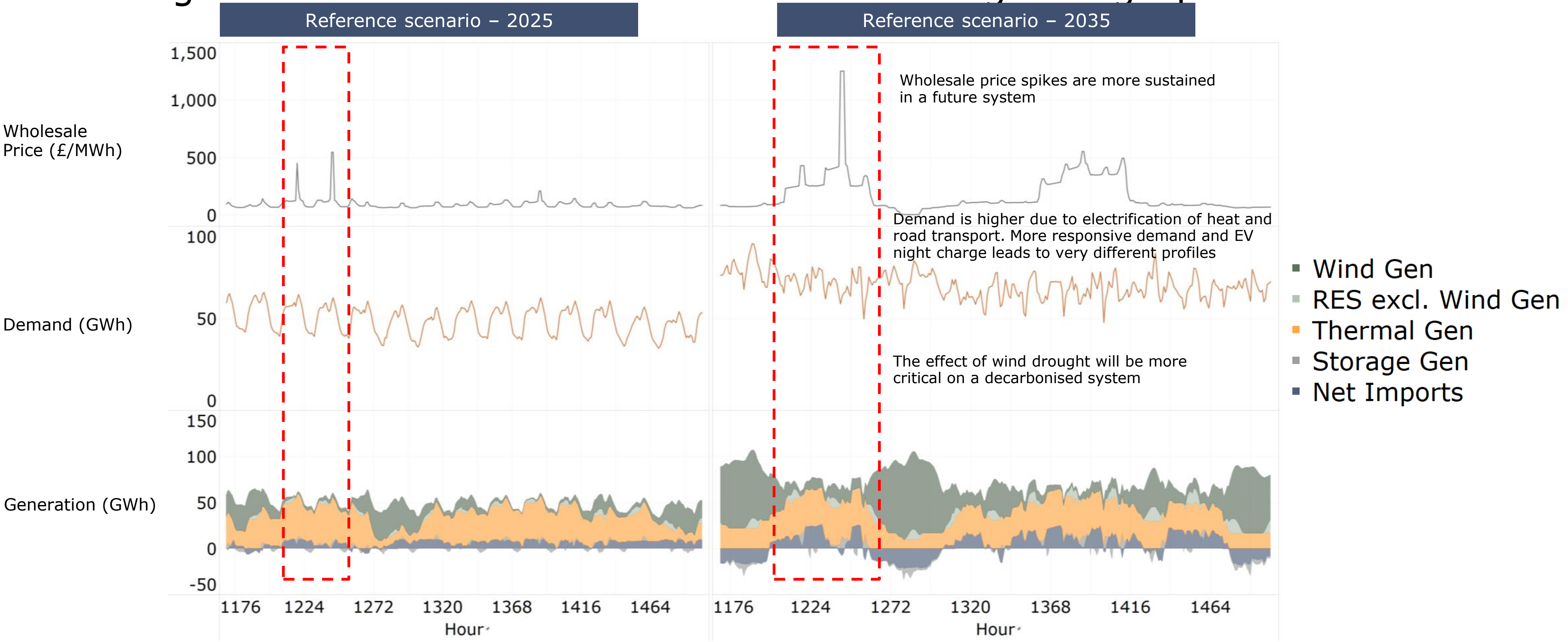
Wind Drought

19 Feb – 3 Mar 1985

Late Feb 1985 was an unusually long period of very low wind speeds, right across NW Europe.

Temperatures were around the seasonal normal (2degC), but a large anti-cyclone sitting across the North Sea brought very low wind speeds of below 5 knots over much of NW Europe. This began in mid-Feb and lasted through until early March, albeit with a brief period of higher wind speeds around 24 Feb of 15-20knots

The diverse generation mix in the ‘Consumer Transformation’ (reference) scenario means that wind droughts can be accommodated; peaking technologies are utilised at times of stress leading to high prices



Wholesale price spikes are more sustained in a future system

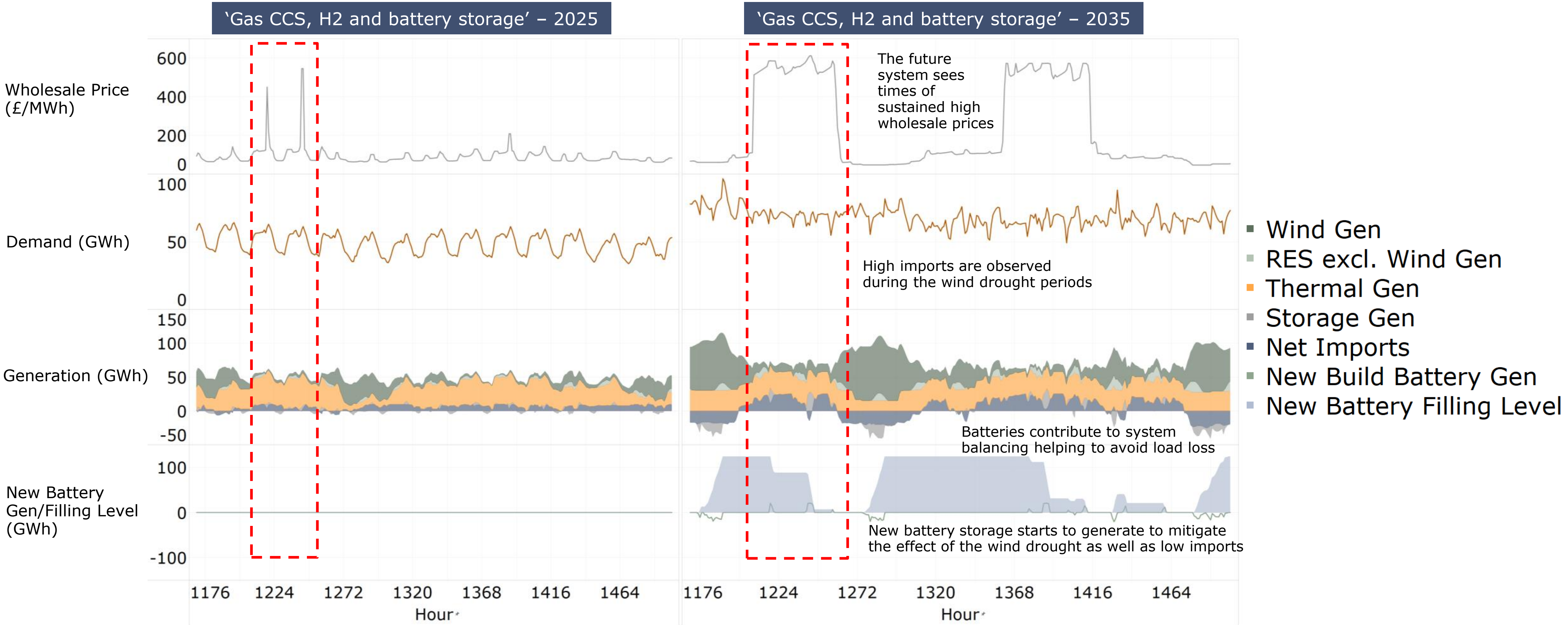
Demand is higher due to electrification of heat and road transport. More responsive demand and EV night charge leads to very different profiles

The effect of wind drought will be more critical on a decarbonised system

Note(s): Weather pattern presented is 1985 for February to the beginning of March; Thermal generation includes demand side response

WIND DROUGHT: “GAS CCS, H2 AND BATTERY STORAGE” CASE

With a decarbonised system by 2035, the effect of wind drought will be more sustained and system demand will be met by imports



‘Gas CCS, H2 and battery storage’ – 2025

‘Gas CCS, H2 and battery storage’ – 2035

The future system sees times of sustained high wholesale prices

High imports are observed during the wind drought periods

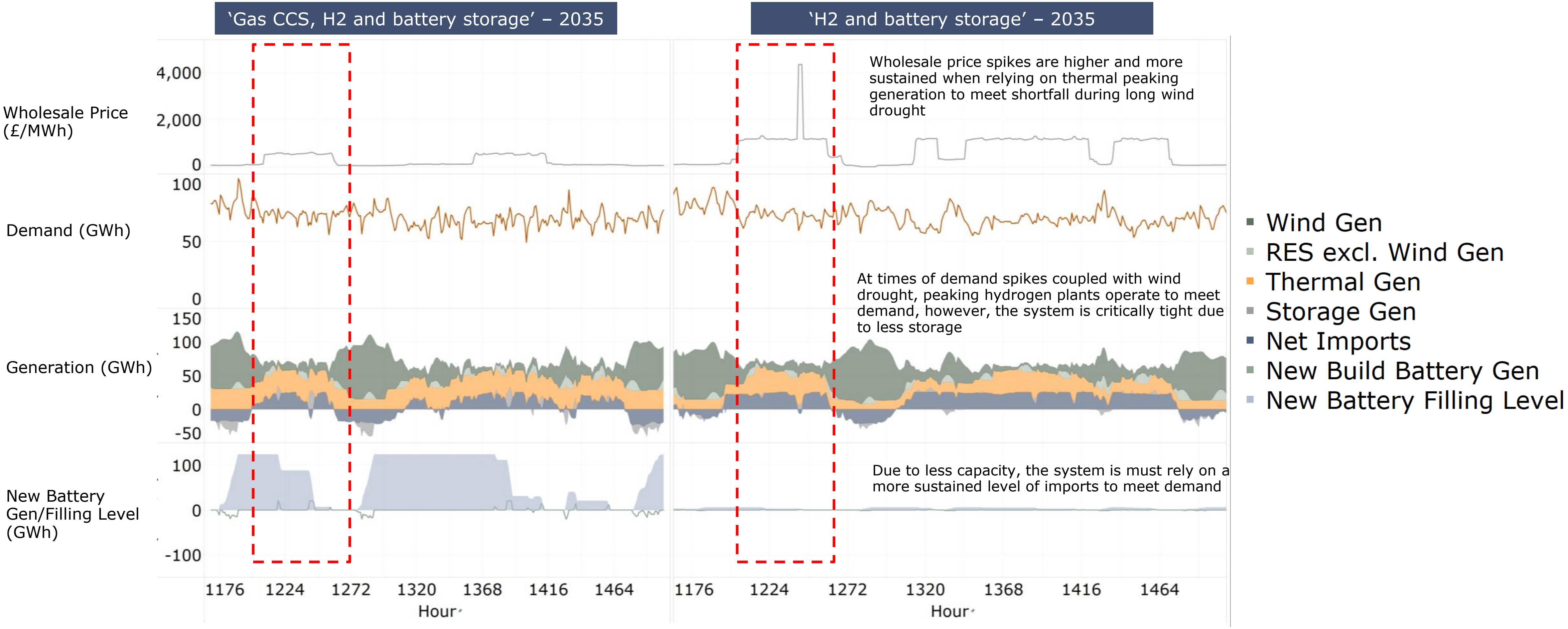
Batteries contribute to system balancing helping to avoid load loss

New battery storage starts to generate to mitigate the effect of the wind drought as well as low imports

Note(s): Weather pattern presented is 1985 for February to the beginning of March; Thermal generation includes demand side response

WIND DROUGHT: COMPARISON OF ‘GAS CCS, H2 AND BATTERY STORAGE’ AND ‘H2 AND BATTERY STORAGE’ CASES

Sufficient battery storage in the ‘Gas CCS, H2 and battery storage’ case mitigates the effect of critical system tightness in wind drought periods



Wholesale price spikes are higher and more sustained when relying on thermal peaking generation to meet shortfall during long wind drought

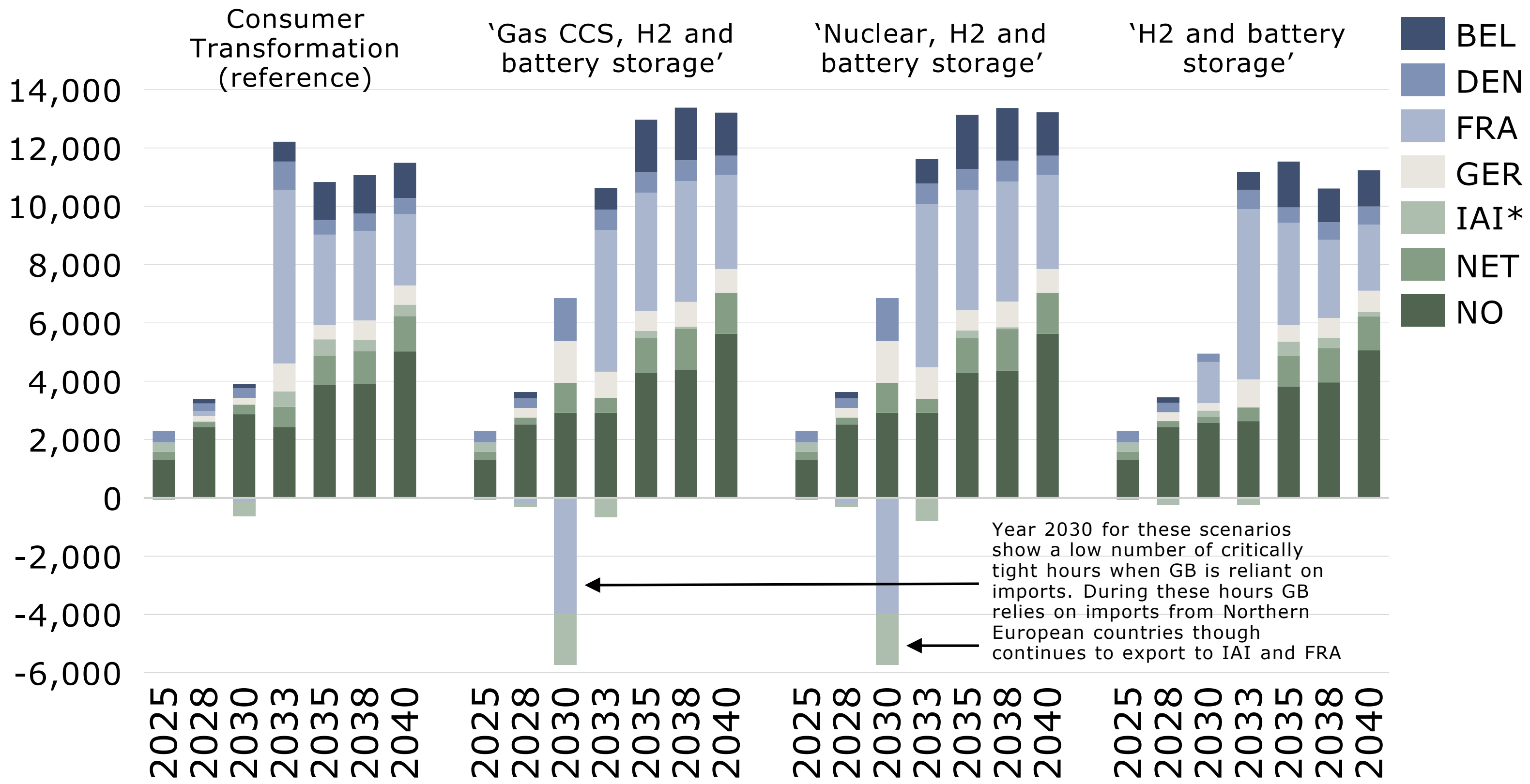
At times of demand spikes coupled with wind drought, peaking hydrogen plants operate to meet demand, however, the system is critically tight due to less storage

Due to less capacity, the system is must rely on a more sustained level of imports to meet demand

Note(s): Weather pattern presented is 1985 for February to the beginning of March; Thermal generation includes demand side response

Future years see a greater reliance on neighbouring countries to provide resilience to the GB system

AVERAGE FLOWS FROM NEIGHBOURING COUNTRIES DURING CRITICALLY TIGHT HOURS WHEN GB IS RELIANT ON INTERCONNECTORS (MW)



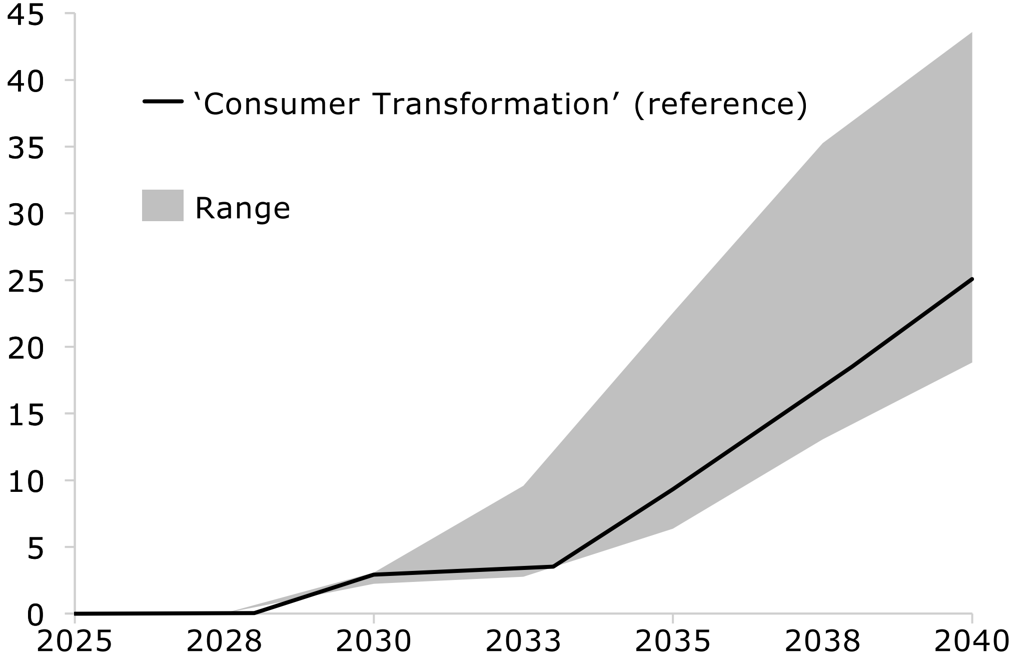
* IAI = Island of All Ireland

- Each scenario uses the same capacity mix for neighbouring countries based on the Consumer Transformation pathway.
- The Consumer Transformation scenarios considers an increase in GB interconnection from 9.8GW in 2025 to 27.0GW in 2040
- Increased interconnector capacity means that GB can receive support from neighbouring countries when the system is tight; while also providing support to neighbours when their system is tight
- When Critically Tight Periods of GB and other countries coincide then imports can be limited and GB can suffer load loss
- GB adequacy is affected by the capacity mix of neighbouring countries and Europe-wide system planning

RENEWABLES CURTAILMENT IN THE DIFFERENT CASES

Assessment of how the resources meet energy throughout the year means that we will need to consider adequacy alongside year-round operability

Curtailment range across all cases (TWh)



Key findings

This study has focussed on how the different resources ensure adequacy. It has not considered how the resources deliver energy to meet demand throughout the year, for example, in periods when demand is much lower and / or output from renewable generation is much higher.

The chart on the left shows the range of annual curtailment due to there being excess supply across our different resource mixes from the dispatch modelling. While the different mixes show similar outcomes for adequacy, the range shows that we operability impacts throughout the year will need to be factored in.

The results here don’t necessarily indicate that some resources are more favourable than others as we haven’t sought to optimise or rebalance the mixes in our study to meet demand throughout the year. However, the findings are qualitatively consistent with other publications such as the Future Energy Scenarios, in that oversupply is expected to be evident in fully decarbonised systems when high output from renewables coincides with lower demand.

This means it will become increasingly necessary to consider the resources needed to ensure adequacy in the context of future operability challenges as well (i.e. we cannot consider adequacy in isolation).

Contents

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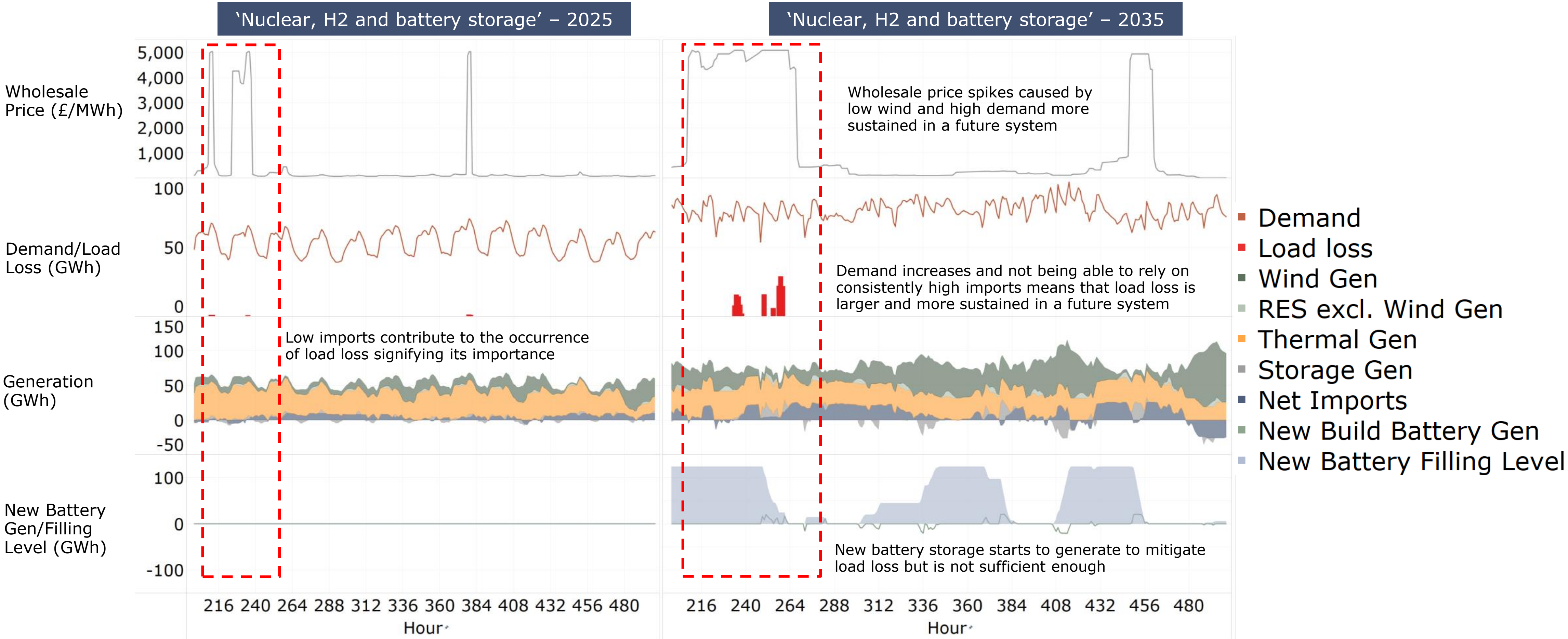
EUROPE-WIDE COLD SPELL: ‘NUCLEAR, H2 AND BATTERY STORAGE’ CASE

With a decarbonised system by 2035, the effect of demand spikes coupled with low wind and imports, will cause a larger, sustained amount of load loss



Low imports contribute to the occurrence of load loss signifying its importance

Wholesale price spikes caused by low wind and high demand more sustained in a future system

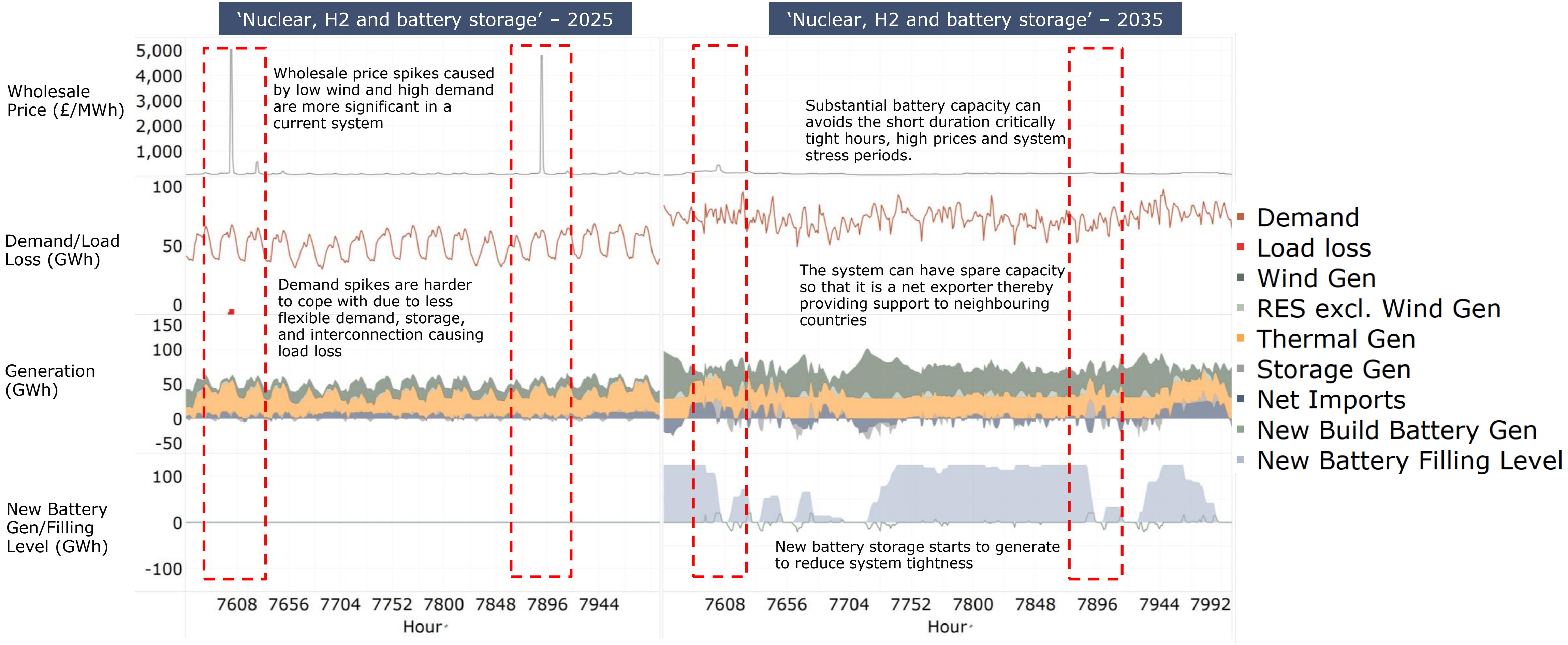
Demand increases and not being able to rely on consistently high imports means that load loss is larger and more sustained in a future system

New battery storage starts to generate to mitigate load loss but is not sufficient enough

Note(s): Weather pattern presented is 1985 for mid-January; Thermal generation includes demand side response

COLD SPELL: ‘NUCLEAR, H2 AND BATTERY STORAGE’ CASE

Flexible demand, storage, and interconnection allow future system to cope with critical weather patterns that result in load loss in the current system



‘Nuclear, H2 and battery storage’ – 2025

‘Nuclear, H2 and battery storage’ – 2035

Wholesale price spikes caused by low wind and high demand are more significant in a current system

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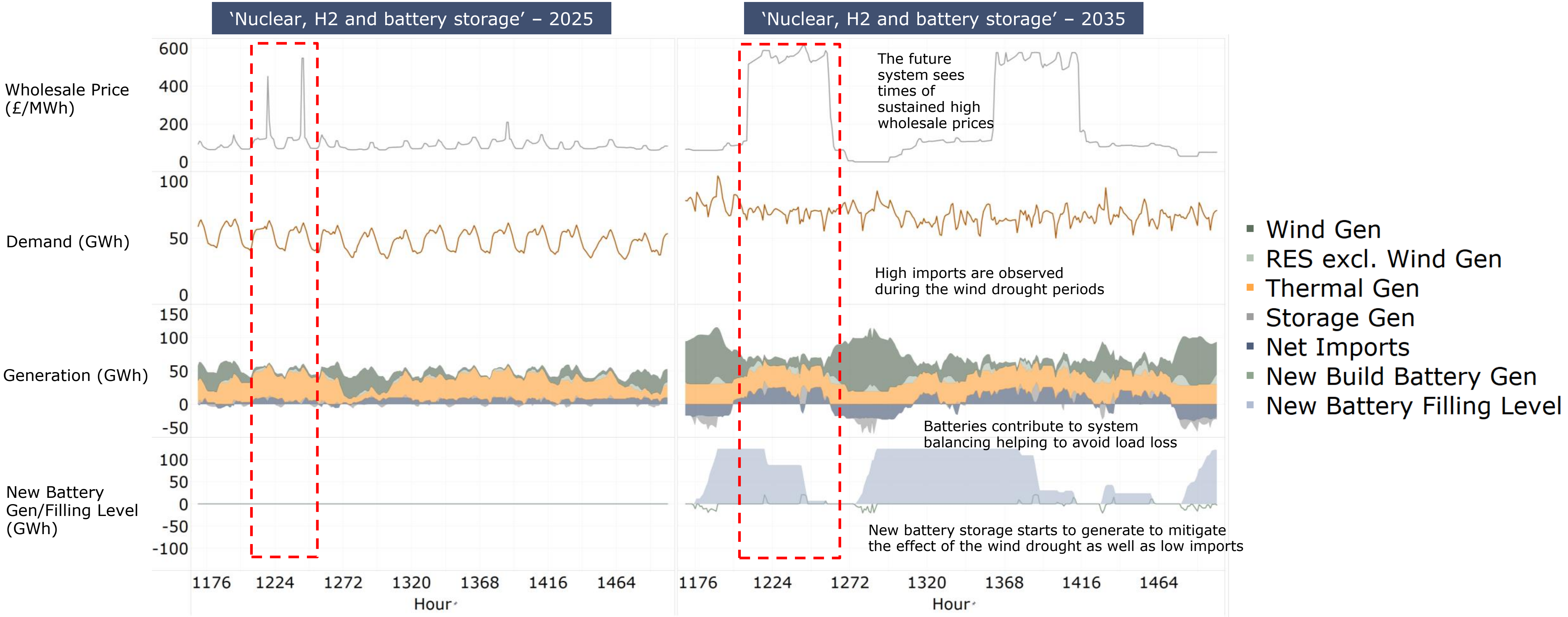
WIND DROUGHT: ‘NUCLEAR, H2 AND BATTERY STORAGE’ CASE

With a decarbonised system by 2035, the effect of wind drought will be more sustained and system demand will be met by imports



The future system sees times of sustained high wholesale prices

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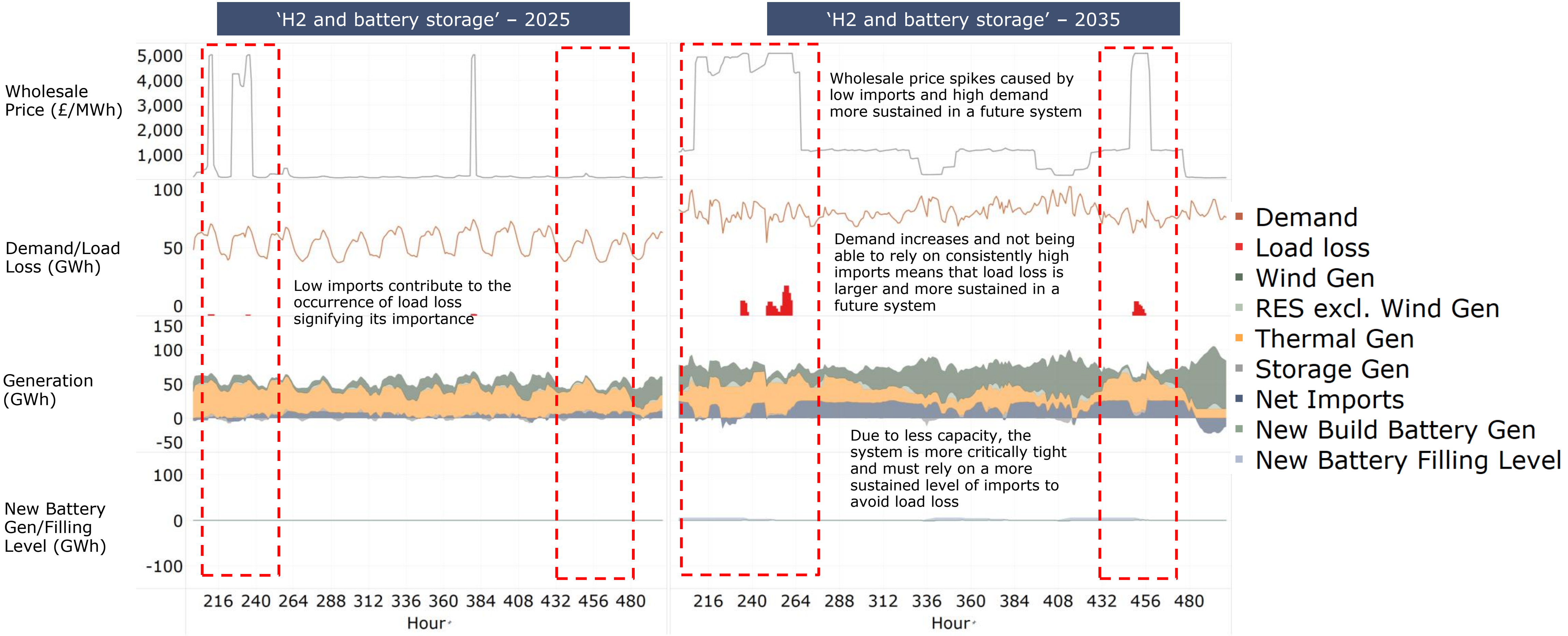
Batteries contribute to system balancing helping to avoid load loss

New battery storage starts to generate to mitigate the effect of the wind drought as well as low imports

Note(s): Weather pattern presented is 1985 for February to the beginning of March; Thermal generation includes demand side response

EUROPE-WIDE COLD SPELL: ‘H2 AND BATTERY STORAGE’ CASE

With a decarbonised system by 2035, limitations on imports coupled with high demand and low wind lead to load loss occurrences



Low imports contribute to the occurrence of load loss signifying its importance

Wholesale price spikes caused by low imports and high demand more sustained in a future system

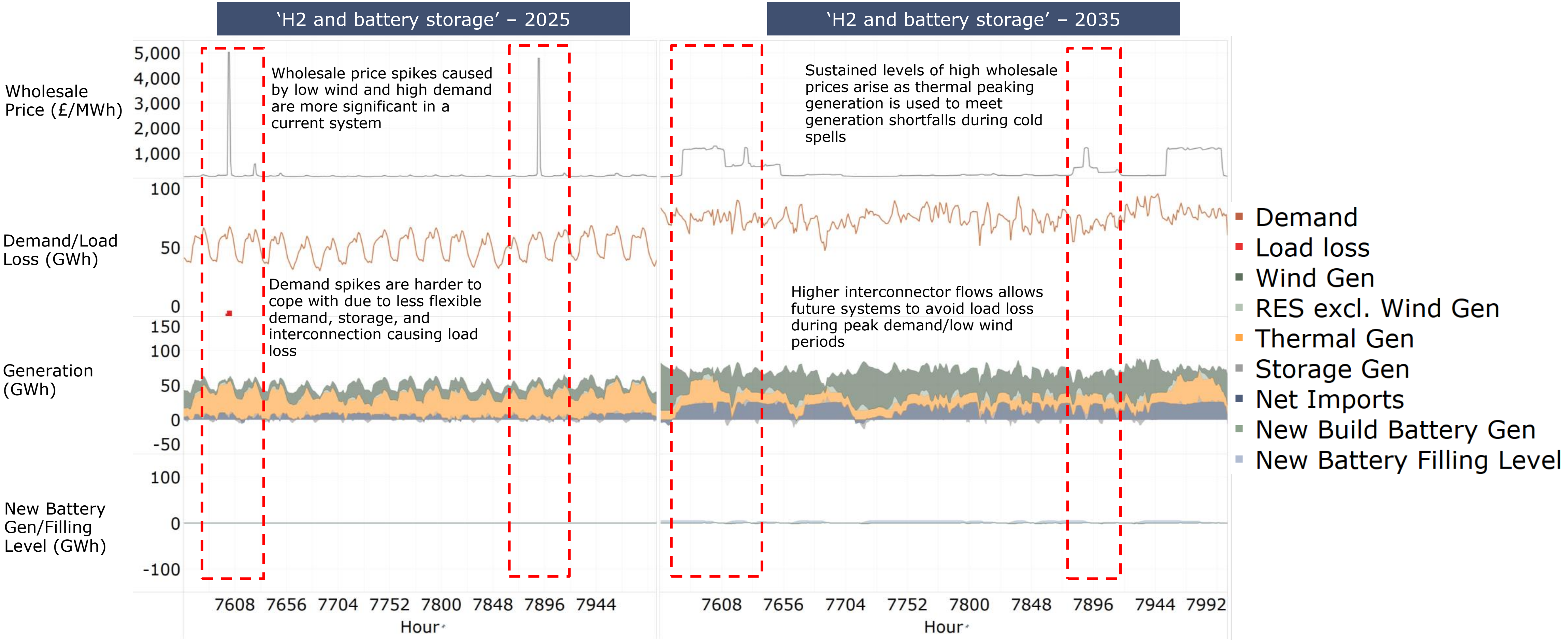
Demand increases and not being able to rely on consistently high imports means that load loss is larger and more sustained in a future system

Due to less capacity, the system is more critically tight and must rely on a more sustained level of imports to avoid load loss

Note(s): Weather pattern presented is 1985 for mid-January; Thermal generation includes demand side response

COLD SPELL: 'H2 AND BATTERY STORAGE' CASE

Flexible demand, storage, and interconnection allow future system to cope with critical weather patterns that result in load loss in the current system



Wholesale price spikes caused by low wind and high demand are more significant in a current system

Demand spikes are harder to cope with due to less flexible demand, storage, and interconnection causing load loss

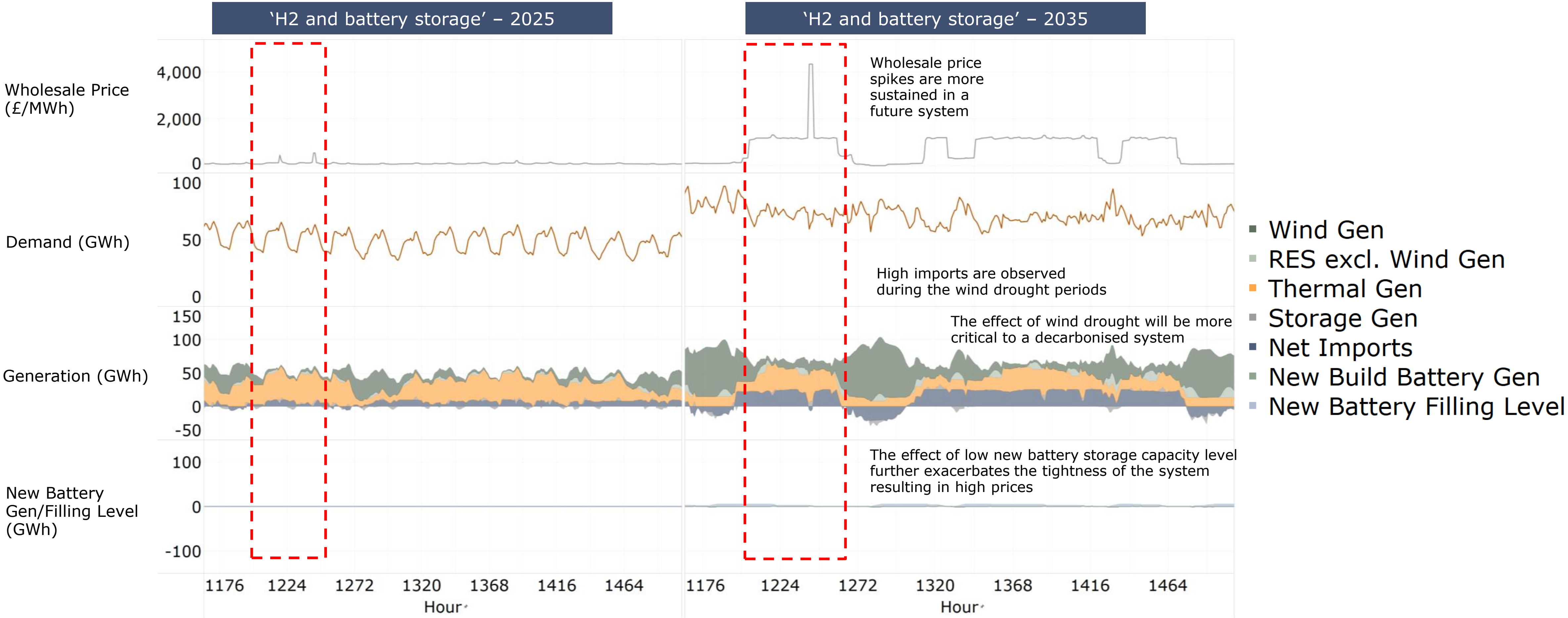
Sustained levels of high wholesale prices arise as thermal peaking generation is used to meet generation shortfalls during cold spells

Higher interconnector flows allows future systems to avoid load loss during peak demand/low wind periods

Note(s): Weather pattern presented is 1985 for the cold spell of mid-November; Thermal generation includes demand side response

WIND DROUGHT: ‘H2 AND BATTERY STORAGE’ CASE

With a decarbonised system by 2035, the effect of wind drought will be more sustained and system demand will be met by imports



Wholesale price spikes are more sustained in a future system

High imports are observed during the wind drought periods

The effect of wind drought will be more critical to a decarbonised system

The effect of low new battery storage capacity level further exacerbates the tightness of the system resulting in high prices

Note(s): Weather pattern presented is 1985 for February to the beginning of March; Thermal generation includes demand side response

Definitions of key terminology used in this report

Characteristic	Definition
Availability	Provider of service is ‘active’ and available to supply service as needed (by the SO)
Critically Tight Periods	Periods of the year where if demand increases by one unit, load loss will happen in the system (either in another period or in another country)
De-rating factor	The contribution of technology to reducing load loss in the Critically Tight Periods. Conventional technologies will have a de-rating factor driven by its availability at these times. Battery de-rating factors are impacted by its storage capability and the energy storage levels during critically tight hours, impacting its generating capability at these times.
Expected Energy Unserved (EEU)	This is the amount of electricity demand - measured in MWh – that is expected not to be met by generation in a given year. This combines both the likelihood and the potential size of any shortfall. Just as in the case of LOLE, the EEU figure should not be taken to mean there will be that particular amount of blackouts, because we expect that in the vast majority of cases, this would be managed without significant impacts on consumers
Loss Of Load Expectation (LOLE)	Used to describe electricity security of supply. It represents the number of hours per year in which, over the long-term, it is expected statistically that supply will not meet demand.
Stochastic outages	The LOLE assessment uses Monte Carlo techniques to evaluate the impact of the different reliability of different types generator. BID3 performs sequential LOLE analysis and for each ‘hour group’ sampling is performed from sets of stochastically generated outage profiles. This defines the overall generator availability

Contents

ABOUT AFRY

AFRY at a glance

SECTOR EXPERTISE

Core sectors:
- Energy
- Bioindustry
- Process Industry
- Automotive
- Infrastructure

ENGINEERING

- Owners/Lenders engineering
- Detail engineering
- Operational services
- Project management & execution
- Technical studies

ADVISORY SERVICES

- Forward looking market analysis
- Strategic advice
- Operational excellence
- Transactions services

DESIGN

- Architecture
- Urban planning
- Digital/UX design
- Lighting & Sound design
- Product design

DIGITALISATION

- Software engineering / development
- AI / Robotics / Drones / 5G
- System integration and management

WE HAVE

16,000

Employees globally
(as of 2021)

ANNUAL REVENUE

1.95 bn

euros in 2021

NUMBER OF COUNTRIES WITH OFFICES

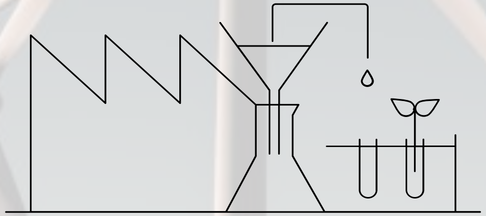
>50

NUMBER OF COUNTRIES WITH PROJECTS

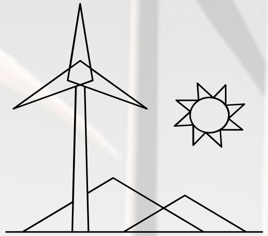
>100

4 GROWTH DRIVERS

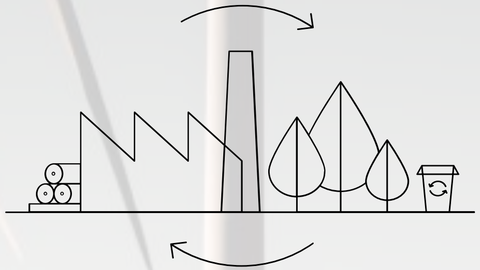
Infrastructure



Food & Life Science



Clean Energy



Bioindustry

AFRY

ÅF PÖYRY