VENICE

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1. Executive Summary

Vulnerability and Energy Networks, Identification and Consumption Evaluation (VENICE) was an Network Innovation Allowance (NIA) funded project which commenced in July 2021 and was completed within the following 25 months following an extension to cover additional analysis of the cost of living crisis. VENICE was a unique project for National Grid Electricity Distribution (NGED) in that it was solely focused on customer vulnerability and specifically looked at assessing and developing methods for customer vulnerability detection and support through the energy transition. The key focus of VENICE was also to produce robust methodologies for local communities to ensure they are supported on their journey to Net Zero without leaving the most vulnerable and fuel poor behind.

The project was developed in collaboration with Frontier Economics, Frasier Nash Consultancy and Wadebridge Renewable Energy Network (WREN) though the following three work streams:

Work Stream 1: led by Frontier Economics and investigated the impact on energy consumption due to COVID 19 and how this could influence energy usage patterns in the future and how these behavioural changes could persist. This work package was complemented by the assessment of the Cost of Living Crisis on customer behaviour at the later stage of the project.
This delivered two reports on the impact of Covid19 and the costs of living crisis on customer behaviour and its persistence.

Work Stream 2: led by Frasier Nash Consultancy focused on research of how customers in vulnerable situations may interact with their electricity differently. Three detection models were developed with the aim to use metering data to detect vulnerable customers not registered on NGED's Priority Service Register (PSR). The learning from the model development has been documented including the approach, findings and limitations. The models were limited by their ability access sufficiently high resolution consumption data so further model development and validation would be required before this could be implemented. A website has been developed to demonstrate how a vulnerability detection model could be used in practice.

Work Stream 3: led by WREN developed better understanding of how the needs of NGED customers will change in the future and understand the role community groups can carry out to support a whole community transition to a Net Zero energy system without leaving anyone behind.

The outputs from this work stream were;

- Community led business propositions and community owned initiatives.
- Community scale Net Zero carbon accounting method and accompanying carbon tool to help communities explore pathways to reach Net Zero futures.
- A Net Zero Community guide to assist community groups interested in planning for Net Zero to help the community to make the transition to a low carbon fugure and make sure that most vulnerable members of the community are supported during this process.

The project has enhanced our work around PSR and Social Obligations by providing new tools and techniques and was completed within the budget of £1.4 million.

2. Project Background

The energy transition is a complex challenge for society and the global pandemic has increased the spotlight on working patterns, mental wellbeing and the changing use of energy. The compexities are exacerbated by the ongoing Cost of Living Crisis which has added additional challeges for the UK and energy sector, including making sure that support is available for customers and specifically customers in vulnerable situations. It is imperative that the energy industry gets a firmer handle on how to respond in this fast changing environment. However, historically it has been difficult for Distribution Network Operators (DNO's), like NGED to gain insights and valuable data into these impacts.

Due to the nature of the energy system predicting energy usage and vulnerability is a complex challenge. Data availability is an additional challenge due to the nature of personal data, the industry structure (supplier hub) and access. Project VENICE aimed to unpick these challenges and to provide DNO's and the industry with tools and insights that could address this particular issue. Specifically, VENICE focused on:

- Exploring how a customer's smart meter data can be used to explore the impact of energy consumption due to COVID19 and how potential behavioural changes may persist.
- Assessing the impact of the Cost of Living Crisis on the domestic electricity and gas consumption and how it translates into increase or decrease of fuel poverty over the analysed timeframe.
- Looking into novel ways of utilising smart meter data to predict consumers becomming vulnerable through development of a variety of change detection models linked to changes in behaviour.
- Engaging with local energy groups, and specifically the fuel poor communities, to ensure DNOs can provide sufficient targeted support and guided advice as needed.

The outputs of VENICE provide NGED and the industry with an opportunity to be more proactive in tackling fuel poverty, vulnerability and the energy transition. VENICE deliverables offer the industry consumer engagement strategies, specifically for local energy groups and local communities, which are often a challenge with fundamental change programmes.

3. Scope and Objectives

The project consists of three work streams as follows:

The first was led by Frontier Economics and looked at the impact of the COVID-19 pandemic on energy networks and how behavioural changes may further impact networks in the future in order to inform network planning.

The second work stream was led by Frazer Nash Consultancy and looked at the challenge of not clearly understanding how to identify, at a granular level, those citizens who require additional support from network operators and energy companies. A substantial amount of work has been done to identify vulnerability at a regional and Lower Layer Super Output Area (LSOA) level, but not at a household level. This project aimed to understand power usage at a household level, by identifying and leveraging underlying trends in smart meter data which predict the likelihood of vulnerability, for example, lower energy usage at the end of a month could indicate a lower income household. This was broken down into three work packages, with two decision points between them. The first was the Dataset Preparation, the second was the determination of the Vulnerability Behavioural Characteristics and Model Development (including validation, verification and dataset acquisition), and the third was the development of the demonstration platform.

The third work stream was led and managed by WREN, a community energy group in the South West of England, and looked at the challenge of meeting Net Zero in a fuel poor community. It explored community schemes and business models to suit vulnerable consumers and provide benefit to the distribution network.

In January 2023, the project was extended to explore the impact of the Cost of Living Crisis on our customers and the network. The extension looked at changes in energy consumption over the winter period 2022-23 and whether there is evidence of increasing levels of vulnerability associated with a significant increase in energy bills.

Table 3-1: Status of project objectives

Objective	Status
Measure the impact of the recent pandemic on networks and in particular persistence of behavioural changes in the future to inform network planning.	✓
Model vulnerability in order to be able to predict if a customer has become vulnerable so that DNOs can improve the identification of vulnerable customers and be able to offer more support to the people that need it.	✓
Use a community energy scheme to determine the right approaches needed to engage the fuel poor in this transition. This will be done via new business models and schemes to attract them to Net Zero while benefitting the electricity distribution network.	✓

4. Success Criteria

Table 4-1: Status of project objectives

Success Criteria	Status
Visualise and Interpret results from both the research on the pandemic and vulnerability analyses.	✓
Create a model of counterfactual demand on the system, to compare pre/post pandemic.	✓
Produce a persistence level report (i.e. how many behaviours will persist post pandemic) and network impact.	✓
Propose community led business models to benefit communities and the distribution network.	✓
Create a methodology for communities developing Net Zero Carbon future scenarios.	✓

5. Details of the Work Carried Out

Each work stream and individual elements of the project are discussed in detail in this section of the report. The struction of this section is as follows: we first discuss Work Stream 1 and specifically this covers the impact of the pandemic on domestic electricity consumption and Electric Vehicle (EV) charging which followed by the assessment of the cost of living crisis on domestic electricity and gas consumption. We then discuss Work Stream 2 which aimed to determine whether it was possible to identify a household in a vulnerable situation from its smart meter data, with a specific detail on all models that have been developed as part of the project effort. Following on from Work Stream 2 we finish off with information about Work Stream 3, also refered to as Net Zero Community (NZCom) work stream. The primary focus of Work Stream 3 was to better understand how the needs of NGED's vulnerable customers would change in the future. We look into novels ways of supporting a whole community through the transition to Net Zero and understand the role community energy groups could play.

Work Stream 1

The impact of the pandemic on domestic electricity consumption

This work package analysed electricity consumption data and drew on behavioural economics to analyse how levels and patterns of household energy use have changed across NGED's network during the COVID-19 pandemic. It considered the extent to which these changes may persist and the implications of this for customers in vulnerable situations.

The impact of the pandemic on individual household electricity consumption was analysed first. Smart meter data from the Smart Energy Research Lab was used for the analysis, which contained half-hourly data consumption over the pandemic period for just under 600 households. This included survey data that could be used to identify household characteristics. Pre-pandemic data then was used to estimate counterfactual electricity consumption patterns, which represented estimated consumption had the pandemic not occurred. Two different predictive modelling approaches were used (a linear regression and machine learning) which modelled each household individually.

A simple way of estimating the counterfactual would be to look at consumption during a year unaffected by the pandemic (e.g. 2019). However electricity consumption is affected by other factors which vary over time – notably the weather, including temperature, sunshine hours and precipitation levels. Such a simple analysis would therefore risk attributing impacts to COVID-19 which were caused by changes in weather. Therefore the decision was made to construct a model which, based on data from prior to the pandemic (the model "training period"), projects what consumption could have been in 2020 and 2021, given factors such as temperature, precipitation, solar radiation, and daily and seasonal trends.

When calculating the difference between the actual and counterfactual consumption patterns, observations by sub-daily periods for weekdays and weekends in a given month were considered. Sub-daily periods are periods of a few hours that tend to represent a group of half-hourly periods where consumption tends to be similar. For example, if sub-period A is of interest (the time between 23:00 and 06:00), on weekdays, in April 2020, for a given household, all data for sub-period A on weekdays in April 2020 was averaged, rather than looking at one specific data point. This gives one consumption value for a specific household in April 2020 for sub-daily period A on weekdays. This is done in order to remove some of the error that comes from idiosyncratic usage (for example, if the washing machine or other high-consumption appliance is in use on any particular day). This allowed to create a counterfactual with less error and bias, but still allowed for identification of the impact on peak demand.

Overall, the analysis showed that actual electricity consumption increased on average versus predicted consumption; which can be attributed to the impact of the pandemic. More specifically, the greatest increases took place during working hours and the greatest changes in consumption occurred during lockdown periods. And whilst on average the effect of the pandemic tended to diminish over the course of the pandemic period, it did not fully diminish for all households.

The changes in consumption for different sub-groups of customers were investigated in two ways.

- First, customer characteristics were picked (based on responses to survey data) and changes in consumption were analysed for those customers. These characteristics were focused on households that, based on our literature review, would either be in a vulnerable situation or changing electricity consumption. This helped to understand whether certain groups of customers (e.g. those in fuel poverty) changed their electricity consumption in a different way to others.
- Then a clustering algorithm to group customers that showed similar behaviours in electricity consumption was used. This allowed to identify specific groups of customers who responded in a particular way but that is not tied to the observable sociodemographic factors in the survey data. This exercise was useful in and of itself, as it demonstrated how fine-grained differences in smart meter consumption patterns (as opposed to overall averages) can be calculated and published, while maintaining customer anonymity.

Finally, the focus of the assessment was on the impact on NGED, considering the impact on vulnerable customers and the network:

- Groups of customers that are likely to be in fuel poverty (customers that self-reported as financially struggling) were identified and the changes in consumption compared with other types of customers were analysed.
- The consideration was given to the the impact on NGED's network. The focus of this work was on the potential risk of constraints if an increase in peak demand seen during the pandemic continues into the future. First, the average increase in peak demand as a result of the pandemic was considered. Then NGED's Network Capacity Map was analysed to calculate the remaining capacity at each substation after adjusting for peak demand. The pandemic effect was added on to the assumed level of peak demand and identified which substations were at or close to reaching capacity.

The second part of theanalysis considered how behaviours might persist. This included mapping the causal relationships that underpin changes to household energy consumption and setting out linkages between the pandemic, changes to household behaviours, and increased/decreased or shifted energy consumption in the home. Crucially, this considered the different customer contexts within which behaviours occur, including consideration of socio-economic and demographic factors, household/dwelling characteristics and seasonal energy requirements, and how these vary across NGED's network.

A behavioural framework on habit formation was then applied. This framework considers how habits are formed and identifies what makes them persist. This can be characterised as the 'Trigger, Action, Reward, Ease' framework. In this framework, a trigger can cause an action. If this action has some kind of reward, that will mean individuals are more likely to repeat the action, particularly if some "efforts" to perform the action first time round don't need to be repeated in order to continue the behaviour. This can be applied to the pandemic as below:

- Trigger: The trigger event is the pandemic, specifically the announcement on 23 March 2020 and the fact that elderly and clinically vulnerable people were advised to 'shield'.

- Action: This led to around 1.5m people in England shielding during March-August 2020, and January-April 2021[1], which meant a stricter set of self-isolation guidelines. Since then, a mass vaccination campaign reduced the risk for these groups, but not eliminated it.
- Reward: Both rewards and costs are relevant to determining the net reward. Social reward is the reward of staying at home, such as reducing the chance of passing COVID-19 to family or friends. Personal reward is the benefit of not catching COVID-19 and making use of online/digital services (e.g. transitioning to online shopping). Personal cost is the cost of staying at home, such as loneliness.
- Ease of persistence: There are two ways this repeated action has primed continued working from home:
  - Individuals have adapted their lives to deal with increased isolation (e.g. ordering groceries online); and
  - Organisations have adapted to cater to those spending more time at home (e.g. virtual GP appointments, home catering, etc).

We applied this framework to the various household groups which we consider of interest from our review of relevant customers in vulnerable situations, thinking about how the pandemic acted as a trigger for new behaviour and how repeated actions during the pandemic (and the potential rewards of these actions) might lead to new behaviours becoming ingrained habits over the course of RIIO-ED2 control period. This provided insights on the medium- to longer-term implications of the pandemic for customers and for the network and, together with the smart meter data analysis, allowed these potential changes to be factored into planning scenarios.

The full detail of the impact of the pandemic on domestic electricity consumption is available here.

Impact of the pandemic on EV charging

This work draws upon and extends the findings from the work described above regarding the general impact of the pandemic on consumption. The work on this was undertaken in four parts:

The first part was to consider the impact of COVID-19 on travel patterns. Specifically it was important to understand how working from home and commuting patterns have changed during the pandemic. Information from government on home working patterns (Office for National Statistics), car travel patterns (Department for Transport) was used to look at possible drivers of car usage in different local areas (focusing on population density and income). This allowed to understand the factors affecting car usage.

Then there was a need to understand how these changes are distributed across customers with different characteristics. The behavioural framework (considered above) was used again to show how likely these changes are to persist. It was applied to commuters who work from home. The rewards and costs of persistent behaviour on different customers were weighted up, judging their relative importance. It was then applied to local areas of NGED's network, hypothesising to what extent car commuters would continue working from home in each local areas.

[1] ONS, Coronavirus and clinically extremely vulnerable (CEV) people in England, https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronavirusandclinicallyextremelyvulnerablepeopleinengland/4aprilto23april2022

The customer characteristics identified in the previous step were taken and mapped on to the likelihood of owning an EV in the future. The consideration was given to the penetration of EVs in local areas using Distribution Future Energy Scenarios (DFES) assumptions. For example, typically affluent and rural areas have greater numbers of predicted EVs.

Finally the persistence of behaviour identified in step 2 and the EV ownership in step 3 were joined up to identify what this meant for charging patterns and peak demand. A “persistence score” was created which measured how likely local areas are to have persistent working from home behaviour. EV uptake was also measured. Taking those scores into account, four types of areas were defined:

- Areas with high EV uptake and high persistence: these areas may see charging demand reduce vs baseline assumptions.
- Areas with high EV uptake and low persistence: these areas may require more network reinforcement as commuters maintain travelling.
- Areas with low EV uptake and high persistence: these areas may require the least reinforcement since there are fewer EVs and persistent working from home.
- Areas with low EV uptake and low persistence: these areas may require the same network reinforcement, but the overall impact is smaller

The impact of the Cost of Living Crisis on domestic electricity and gas consumption

This work uses the same approach to data analysis as the analysis on the impact of the pandemic on electricity consumption, but focussing on the effect of the Cost of Living Crisis. Smart meter data from the Smart Energy Research Lab was used, which contains half-hourly data consumption over 2021 and 2022 for around 6,500 households (a significantly larger sample than sample for analysing the impact of the pandemic).There were a couple of key differences in the analysis for the cost of living crisis compared with our previous work.

First, both gas and electricity household consumption was analysed. Gas consumption is relevant to NGED as it will drive overall fuel poverty, and it is also a proxy for how heating demand changed in general (a large proportion of this demand may be served by electric heat pumps in the future).

Second, aggregate daily consumption was included in the analysis rather than sub-daily consumption. More granular data was not needed since, unlike the COVID-19 work, the increase in peak demand was not expected. In addition, the within-day pattern of gas consumption would not be particularly useful for NGED, as heat pump demand will likely follow a very different profile. The use of daily data had advantages as it meant results for each household were obtained which were less likely to have bias or error.

The use of the smart meter data allowed to estimate the overall impact of the Cost of Living Crisis on energy consumption, and therefore bills and fuel poverty. This was carried out both for the entire sample, and also for different groups of customers (focussing in particular on those in vulnerable circumstances).

In addition to the consumption data, a survey in January 2023 was undertaken to identify specific behaviours in response to the Cost of Living Crisis and relevant household demographics. The household information from this survey was matched with the household consumption data.

This allowed to observe the effectiveness of each action in reducing consumption, whether and how this effectiveness varied by customer group, and the impact of actions on bills and ultimately fuel poverty.

Work Stream 2

Vulnerability detection models

VENICE Work Stream 2 aimed at determining whether it was possible to identify a household in a vulnerable situation from its smart meter data. To address this, an approach combining the behavioural sciences, data analytics and social value quantification was adopted to:

- Determine how customers in vulnerable situations may interact with their electricity differently.
- Develop models to identify these behaviours within a households smart meter data.
- Determine the social value of using a vulnerability detection model to identify and add customers to the PSR.

The following sub-sections discuss each element separately.

How customers in vulnerable situation may interact with their electricity differently

This work started with a literature review, which covered academic and grey literature relating to vulnerability in the energy sector. The purpose of this was to consider how vulnerability had been defined in previous research, and to take into account the myriad of factors affecting vulnerable consumers and circumstances. Second, a series of stakeholder workshops with NGED and charities or support organisations were carried out. This consultation enabled a wide range of expert opinions to be gathered, helping to verify and complement findings from the literature review relating to factors affecting vulnerability, and how these might manifest within energy usage. Project research comprised of behavioural scientists with experience in conducting literature reviews, stakeholder workshops and applied data analysis.

Several overarching conclusions were drawn as a result of this research effort:

- The use of a probabilistic model of smart meter data for the purposes of predicting vulnerability was supported, given the complex and transient nature of vulnerability.

- The impact of vulnerability is likely to vary greatly across households and time, and certain vulnerabilities may be more detectable than others.

- Data gathered from smart meters should be considered in conjunction with other sources of available information, such as account history and known household characteristics. Triangulation is likely to improve the quality of predictions relating to vulnerability, and crucially, smart meter data seems likely to be capable of providing incremental utility to the accuracy of that prediction.

- It was suggested that the use of smart meter data for the proposed purposes would be of benefit for consumers, suppliers and network operators. A case could be made for operators to independently have access to such data, to allow them to understand, support and anticipate consumer circumstances and energy demands during the transition to Net Zero.

Full details of this work can be found here.

Develop models to identify change in behaviours within a households smart meter data

Three separate models were developed, with each one identifying a different type of behavioural characteristic in smart meter data that may be indicators of vulnerability. There are:

- Cohort Comparison: This model is used to identify vulnerabilities related to the overall level of usage a specific household has.

- Appliance Disaggregation and Prediction: This model is used to identify vulnerabilities related to appliance usage.

- Overall Changes in Usage: This model is used to identify vulnerabilities related to a significant change in its occupants' behaviour.

Each model was developed and tested in isolation using different datasets. For a majority of the project, open-source datasets were used.

Appliance Disaggregation and Prediction Model

The appliance disaggregation prediction model aimed to identify which appliances were being used from 30-minute smart meter data. This was done by determining the likelihood the power drawn in a 30-minute window was from each combination of appliances and multiplying this by the probability each appliance is used in that specific 30-minute window. This probability is iterated upon to become specific for each household and appliance. The key model limitations are driven by high uncertainty in the power drawn by an appliance, as expected. These conclusions show that the approach has shown some potential, but highly dependent on having a high resolution smart meter data (i.e. of 1 minute or higher). Smart meters that are being rolled-out in the UK are not set up to capture consumption at this level of resolution

Cohort Comparison Model

The cohort comparison model aimed to identify households that used comparatively less or more electricity than anticipated, given the households characteristics. The model was developed using a proxy for household characteristics and average usage data. The results confirmed that some of the variation in a household's average usage could be attributed to the characteristics. To develop the model further, more testing must be undertaken with real average household usage data for homes with known characteristics.

Overall Changes in Usage Model

The aim of this model was to develop a data driven model to help identify sustained changes in the energy usage patterns for a household. These changes do not necessarily indicate the onset of a vulnerability as opposed to a general change of circumstance, but, are a first step in a broader process of identifying households for which further investigation may be valuable.

The change detection model conceptually splits a household's usage into a training set. During training, the model removes sporadic peaks in usage and determines the baseline variation. These baseline usages are clustered into four types of day: typically a quiet day, a busy day, and two days somewhere in the middle. For new usage from the household, the model determines if the behaviour fits into the classified 'types' for that household. If a period of days does not consistently fall within a known 'type', then a change is highlighted. In addition, the model investigates the changes in the proportion of each cluster within the household, and if there is as a significant change to more of one 'type' of day, then a change is highlighted.

The model was tested by artificially adding changes into the household usage that represent a new vulnerability[2]. These changes were designed to be consistent with the variation seen across the real households within the dataset. The results showed the model could accurately detect most of the changes added. There were some false positives over specific periods of the year, such as Christmas. If this model were to be implemented, additional contextual information could be added to reduce the importance of changes seen in specific days or periods.

Further information about the model and the dashboard developed for demonstration purposes is available here.

Datasets

For a majority of the development, each model was trained and tested using open source datasets, and therefore none have been validated using real households with known vulnerabilities. This was due to the restrictions in place which limit smart meter data access to DNOs and the public. During the project, we tried to obtain smart meter data from vulnerable households through direct communication with consumers, through energy support companies and directly from suppliers. However, none of these proved fruitful until the final stages of the work, when a smart meter dataset was sourced form Hildebrand Technology Ltd. This contained energy usage and associated metadata for numerous households across the UK, and was subsequently used for the development of the 'Overall Changes in usage' model.

Due to this lack of validation and realistic training data, currently, none of these models are ready to be deployed or used by DNOs.

Full details from this work package can be found here and here.

Work Stream 3

NZCom work package was developed to better understand how the needs of NGED customers will change in the future and understand the role community groups can carry out to support a whole community transition to a Net Zero energy system without leaving anyone behind. The project consortia brought together expertise in energy policy and carbon accounting from University of Exeter, skills in energy system modelling and strategies from Planet A Solutions (Planet A), experience of barriers facing customers in vulnerable situations and community energy business models from Community Energy Plus (CEP), support from the Centre for Energy Equality to develop an online tool for community users, as well as the knowledge and trusted relationship with the Wadebridge and Padstow Community Network Area (the community) from Wadebridge Renewable Energy Network (WREN).

At the start of the project a dynamic community engagement plan was developed that identified the types of stakeholders to engage with, appropriate methods to keep the community engaged, and rules of engagement set out. The plan was continually revisited and revised as the project progressed.

The community engagement plan identified the need for different levels of stakeholder engagement across the project, which led to the establishment of three steering groups to perform the roles of critical friends to NZCom. These were:

- Independent project advisory group – formed of senior representatives from local councils, community support groups and other relevant organisations.

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[2] Vulnerability features were assumption based.

- Community focus group – formed of residents and businesses of the Wadebridge & Padstow Community Network Area.

- Peer review group – formed of representatives from other Cornish community energy and climate action groups.

The steering groups provided feedback on project plans, identified gaps in project research, methodology or approach, risks associated with the project aims, objectives and deliverables, provided strategic advice and comments on project outputs, offered contextual advice on the wider Net Zero transition and other local support for vulnerable members of the community, helped to align and integrate NZCom with other relevant local activities, identified potential new opportunities for NZCom as they arise, and extended the reach of NZCom through their personal/ professional networks.

In order to fully understand the impacts of the Net Zero transition it was necessary to agree on a definition of vulnerable consumers. There is a clear definition from Ofgem of vulnerability in the domestic energy market. However, non-domestic consumers are not afforded the same protections and are not covered by a similar "Vulnerability Commitment" available to domestic consumers - a legal safety net for debt and disconnection. Given the greater diversity of characteristics for businesses, defining vulnerability is significantly harder and it is therefore difficult to identify the benefits that a non-domestic PSR could provide.

The success of the Net Zero carbon transition process in the non-domestic energy sector will depend on a complex mix of clear relevant information, resource availability, practicality, technology, government policy and consumer response, as well as the necessary motivation to change, be that in personal intent or in response to financial necessity.

The project set out to define the Net Zero challenge facing the community, with respect to power, heat and transport, and what the potential paths to transition are. It started with Uiversity of Exeter's review of existing energy scenario analyses undertaken in the UK and reflected upon their relevance and context.

The NZCom future energy scenarios were developed by adapting established relevant scenario frameworks to incorporate a bottom-up Intuitive Logics approach specific to the community. In particular, the National Grid Future Energy Scenario (NG FES) framework and NGED's DFES, upon which additional critical uncertainties relating to speed of decarbonisation and scale of societal engagement, along with additional points of uncertainty of relevance to vulnerability for the community and other local challenges.

While many of the high-level assumptions made within the NG FES and DFES were adopted, new assumptions of particular relevance to the community were also articulated within the developed methodology. It was also acknowledged that without considering the vulnerabilities of individuals and households, there is a risk that progress towards Net Zero exacerbates existing inequalities or creates new forms of injustice.

Co-producing scenarios concurrently and iteratively across other project activities and with input from the steering groups meant they were a) more likely to reflect local views about energy system change and b) more likely to be of practical use to decision makers.

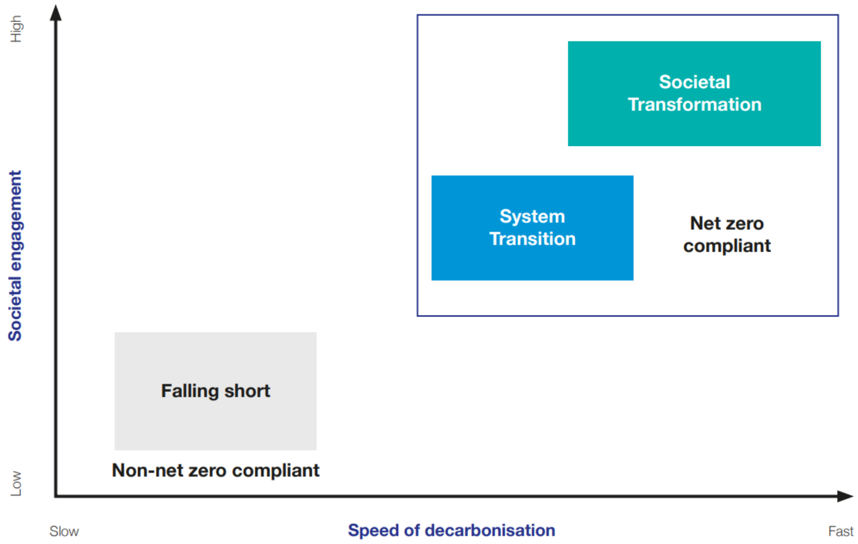

Figure 1 Interaction of scenarios with energy flows and carbon modelling

Three scenarios for the community were developed through the identification of 'branching' and 'bridging' points, e.g. key decisions or other tipping points that favour support specific technological pathways over others. The scenarios described future energy systems in which technologies and infrastructures have co-evolved alongside societal and behavioural factors. Technological options are constrained and enabled by societal engagement, whilst societal engagement – and the ability to engage with vulnerable parts of the community - are shaped in turn by technologies and infrastructures.

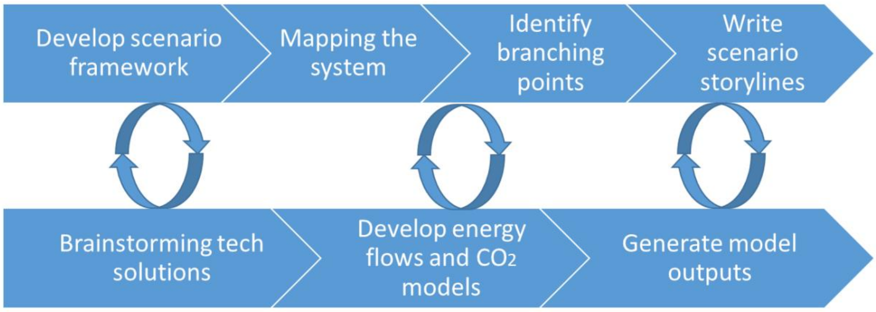

Figure 2 NZCom Future Energy Scenarios Framework

One of the key considerations for scenarios is being able to measure, monitor and evaluate progress. University of Exeter also developed a Green House Gases (GHG) accounting method that provided a baseline for the community (based on available data) in terms of buildings and transport. In addition, the accounting methodology allowed for the future assessment of the effects of different interventions, such as adoption of lower carbon energy technologies, and changes in energy consumption behaviours. The methodology was developed to be easily replicated and implemented by other communities.

The main limitation of the accounting method developed was the focus on stationary energy[3] for residential, industrial and commercial use, as well as road transport (in terms of emission sources), and scope 1 and 2 emissions (in terms of the coverage of emissions of different scopes).

Whilst the scenarios and carbon accounting methodology were being developed, Planet A were reviewing different technical and system interventions to reduce GHG emissions, whilst meeting the community's future requirement for electricity, heat, transport and cross vector energy. These options were ranked in terms of technical feasibility, regulatory feasibility, GHG emissions reduction, community benefit and ease of delivery.

A full assessment of the confining factors (market/ technology readiness, availability/ access to data, network capacity, skills and training, building stock suitability, social, financial, geographical and legal) and constraints (policy and regulatory) of the shortlisted options was completed to prioritise those that were deemed to have the most impact in rapid decarbonisation.

A model of the community (13,417 homes) was developed to be able to assess the impact of different low carbon options on carbon equivalent emissions (CO_{2e}), cost and energy consumption, across the three energy scenarios out to 2050. The model considers a lot of data variables, including heating and hot water systems, house types and size, energy efficiency rating, domestic mileage, current energy costs (across all fuel types) and inflation rates.

The results of the complex community model were summarised into a number of tables within a Microsoft Excel tool which were translated into an online 'Future Energy Tool', developed by the CEE, along with a supporting user guide. The online tool allows other community groups to set up a model of their community and set out the timescales in which they would like to see energy efficiency measures, solar PV, heat pumps and electric vehicles rolled out. When a community model is set up this can be shared, and from this individuals can create their own home and personal journey to Net Zero.

A pseudo microgrid was presented by Planet A as the final recommended intervention, to meet the objective of delivering a just and fair energy transition without leaving anyone behind in the community. The pseudo microgrid seeks to replicate the advantages offered by a private microgrid in terms of shared local energy whilst using the distribution network infrastructure downstream of a designated boundary point, e.g. substation. The advantages provided by a pseudo microgrid come from the ability to exchange local energy between generators and customers, without incurring the additional national system charges and final consumption levies[4]. Multiple pseudo microgrids may be required to cover a whole community area, with each microgrid being defined by its local low voltage or high voltage substation.

[3] The energy used within the buildings rather than the energy used by the occupants whilst not in the building, with the exclusion of public and private raid transport.

[4] It should be noted that implementation of a presudo microgrid would most likely trigger a review of Distribution Use of System (DUoS) charge structure to ensure fairness to all customers.

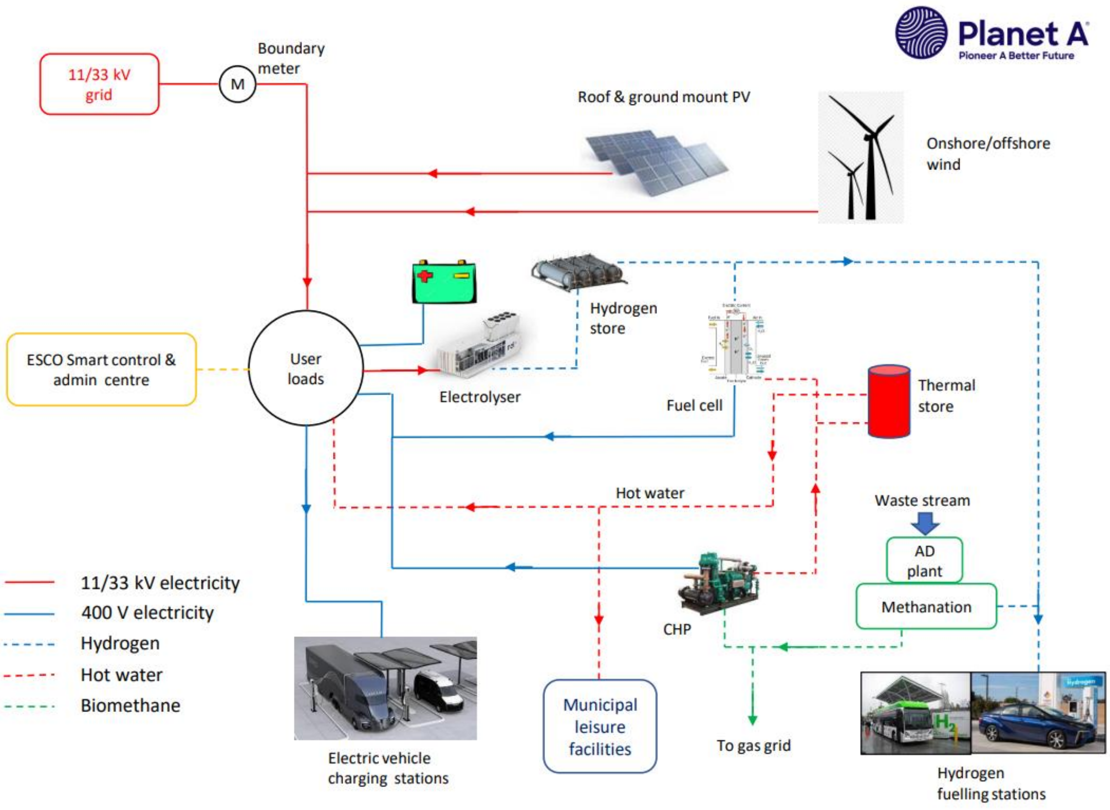

Figure 3 Pseudo microgrid concept

The delivery mechanism of one or more pseudo microgrids for the community was assumed to be via a community operated Energy Service Company (ESCO), whereby the locally generated energy is sold to homes at an advantageous price compared to ordinarily supplied energy from a utility's provider[5]. In the NZCom scenario, the ESCO applies a four-tiered tariff that increases the cost of energy as more energy is used. Therefore, in principle, the lower energy users in smaller more efficient homes, or those that are frugal with their energy use (likely to be those who have the least expendable income and therefore may be classified as vulnerable), have their energy costs subsidised to a degree by the higher energy users (e.g. those in larger homes or are energy extravagant). It is however recognised that this system should be fine tuned so that the higher energy user do not include fuel poor (e.g. a large family living in an poorly insulated dwellings).

From the modelling completed it was established that heat is the most significant challenge for the community to transition to Net Zero. Planet A went on to develop a strategy to mitigate the inevitable impact of heat electrification on distribution system costs (which ultimately increase the cost to the consumer), while also, fairly billing heat pump consumption to incentivise and accelerate the uptake of Net Zero heating.

Reducing consumer energy costs with an innovative heat pump tariff and peak avoidance strategy had two elements. The first was a time-of-use (ToU) tariff which excludes green levies from heat pump consumption and incentivises peak load reduction. The second element is several peak avoidance strategies which help consumers benefit from the proposed tariff and help reduce peak

[5] It is important to note that this is a significant assumption that the local generation is sufficient to cover all local demand and that ESCO cost of energy is cheaper than the wholesale market.

demand. From the modelling completed it was found that the tariff has the potential to save consumers up to 25% on their heat pump running costs, by avoiding the 'red band' period between 4-7 pm. The amount of load possible to be shifted depends on the thermal properties of the house and the peak avoidance strategy employed[6]. Depending on the number of heat pumps taking this action there is the potential for this intervention to cause a second higher demand peak at the substation level.[7]

Planet A are now taking forward a **Warmth-as-a-Service (WaaS) trial through Ofgem's Innovation Link Sandbox scheme,** where an energy supplier will provide a fixed fee contract to customers with electric heating systems to keep their home at a specified temperature during an agreed schedule of 'warm-hours'.

Following on from the interventions proposed, CEP looked at the possible socioeconomic outcomes that can be achieved from different community business models and structures. A number of community business case options were presented, which could be considered by any community group to support their own energy transition goals. A specific recommendation for WREN (a Low Carbon Energy Adviser) was determined as delivering the most benefit to the community, through supporting vulnerable consumers (domestic and non-domestic), promoting and supporting the uptake of low carbon technologies.

It is acknowledged that WREN was in a privileged position to lead NZCom and have the support of very high skilled and knowledgeable project partners to develop recommendations for the community. Therefore, the final stage of the project was to translate the journey that had been taken through NZCom in to a succinct simplified and replicable process for other communities to follow. To this end a guide for communities was produced and launched at the 'Your Energy Transition' event, a day dedicated to local people, households, community groups & businesses in the collective journey to a Net Zero future. The guide will continue to be promoted and shared as part of the project legacy.

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[6] Similar results have been obtrained during NIC Equinox trial one showing that customers can generally interrupt heat pump operation for up to two hours with little impact on comfort: www.nationalgrid.co.uk/downloads-view-reciteme/639583

[7] Equinox trial one provided evidence that a temprory increase in demand is present in households following flexibility events: www.nationalgrid.co.uk/downloads-view-reciteme/639583

6. Performance Compared to Original Aims, Objectives and Success Criteria

Table 6-1: Performance compared to project objectives

Objective	Status	Performance
Measure the impact of the recent pandemic on networks and in particular persistence of behavioural changes in the future to inform network planning.	Complete	The project team developed hypotheses on changes in electricity consumption in response to the pandemic and the likely persistence of these changes. The hypotheses were then tested through the analysis of smart meter data. The hypotheses were generated on the basis of a literature review and emerging published data, and the application of a behavioural framework around habit formation. The complete information about the methodology applied and full detail on the results are available here. The analysis also included the investigation of EV uptake on NGED's network in light of the pandemic, assessing implications on the NGED business plan assumptions.
Model vulnerability in order to be able to predict if a customer has become vulnerable so that DNOs can improve the identification of vulnerable customers and be able to offer more support to the people that need it.	Complete	Three different approaches to detect vulnerability patterns in electricity energy usage data were developed. The modelling approaches included: 1) the cohort comparison model, 2) the appliance disaggregation and prediction model and 3) the change detection model. Each model was developed and tested in isolation using different, open source, datasets. Whilst the open source datasets were used to develop each model, none were validated using real households with known vulnerabilities. This was due to the restrictions in place which limit smart meter data access to DNOs and the public.
Use a community energy scheme to determine the right approaches needed to engage the fuel poor in this transition. This will be done via new business models and schemes to attract them to Net Zero while benefitting the electricity distribution network.	Complete	Through the development of a dynamic energy model for the defined community and a greenhouse gas accounting methodology, the impact of different interventions and future energy scenarios were assessed, leading to the development of new community business models that have the potential to better support vulnerable customers in the transition to net zero. Further information is available here.

Table 6-2: Status of project success criteria

Success Criteria	Achieved	Performance
Visualise and Interpret results from both the research on the pandemic and vulnerability analyses	✓	Changes in overall domestic electricity consumption that may be attributed to the pandemic have been investigated both month-by-month and for specific sub-daily periods. The changes have then been analysed by customer subgroup, when finally a regression analysis was used to test for relationships between consumption changes and customer characteristics. Further information is available here.
Create a model of counterfactual demand on the system, to compare pre/post pandemic	✓	The counterfactual consumption is an estimate of what consumption could have been absent the impact of the pandemic. The model was constructed based on data prior to the pandemic and projected what consumption could have been in 2020 and 2021, given factors such as temperature, precipitation, solar radiation, and daily and seasonal trends. The modelling of the counterfactual was carried out using LASSO regressions and a neutral network. Full detail is available here.
Produce a persistence level report (i.e. how many behaviours will persist post pandemic) and network impact	✓	A persistence level analysis was performed and indicated no observed increases in domestic electricity consumption in aggregate as a result of the pandemic. However, there is some evidence of specific household groups having sustained increase in consumption. Those with persistent changes in electricity consumption are likely to make a small proportion of the population (i.e. only 8% of our sample and include households with children and working from home). On the implications for NGED's network planning, the analysis suggests that there is likely to be little lasting impact of the pandemic on behaviours affecting electricity consumptions, and any lasting impact may be affected by the ongoing cost of living crisis. Full detail available in the report here.
Propose community led business model to benefit communities and the distribution network	✓	A number of community business case options were presented, which could be considered by any community group to support their own energy transition goals – available here. A pseudo microgrid solution, WaaS and the potential to reduce customer energy costs with an innovative heat pump tariff and peak avoidance strategy were considered to meet the objective of delivering a just and fair energy transition without leaving anyone behind in the community.
Create a methodology for communities developing Net Zero Carbon future scenarios	✓	The Net Zero community future energy scenarios were developed by adapting National Grid FES and NGED's DFES, upon which additional critical uncertainties relating to speed of decarbonisation and scale of societal engagement, along with additional

Success Criteria	Achieved	Performance
		points of uncertainty of relevance to vulnerability for community and other local challenges. Specific new assumption of particular relevant to the community were also articulated within the developed methodology (available here).
The project was extended to establish a better understanding of the Cost of Living crisis on NGED customers and the network	✓	A set of hypotheses, based on a review of the literature and available information, have been formulated. Actions taken by customers and changes in customers behaviours assessed. The difference between obsetved amd predicted consumption behaviours established.

7. Required Modifications to the Planned Approach during the Course of the Project

There has been a number of change requests throughout the course of the project which were processed and documented in accordance with NGED's Innovation governance.

The change requests covered the following elements of work:

- An additional piece of work was added to Work Stream 1 to investigate whether the pandemic would further impact assumptions around EV charging behaviour.
- Frazer-Nash Consultancy subcontracted Hildebrand Technology Limited to obtain access to smart meter data to support development of the vulnerability detection models.
- The Cost of living crisis analysis has been added to the original scope of works to evaluate its impact on customer behaviour and NGED demand.
- NGED's project management budget was increased due to extention of the project for an additional 8 months.

8. Project Costs

Table 8-1: Overall Project Spend (£)

Activity	Budget	Actual	Variance (%)
Frontier Economics	243,000	466,041	+92%
Frasier Nash Consultancy	405,000	437,854.6	+8%
WREN	398,531	353,781	-11%
NGED PM & Dissemination	95,273	122,929	+29%
NGED Information Resource	50,000	20,000	-60%
Smart Meter Data Provision	100,000	32,330.60	-68%
British Gas	50,000	0	-100%
Totals before contingency	**1,341,804**	**1,432,936**	**+7%**
Contingency	134,180.4	0	-100%
Totals with contingency	**1,475,984**	**1,432,936**	**-3%**

Further detail on the budget variation is provided below:

- Frontier Economics' budget was increase to cover expense for the additional pieces of work (EV charging change due to COVID 19 and Cost of Living Crisis)
- Frasier Nash Consultancy original budget was increased to cover the cost for sourcing smart meter data and support with dissemination (i.e. CIRED 2023 conference)
- Change of the PM allowance (£30k) was due to the extension of the project by additional 7 months.
- During the course of the project it was decided that support of NGED's Information Resources is not required and the portion of that budget was used by NGED PM.
- Only a portion of the funds budgeted for purchasing of the smart meter data was required.
- British Gas was not participating in the project and therefore didn't book to the project.

9. Lessons Learnt for Future Projects and outcomes

Smart Meter Data

- Access to smart meter data was an ongoing challenge affecting both the impact of the COVID-19 pandemic work performed by Frontier Economics and modelling activities completed by Frazier Nash Consultancy. However, there are benefits to DNOs in accessing individual smart meter data which could provide benefits to customers.
- Having access to smart meter data meant using some analytical techniques such as linear regression and machine learning to predict energy consumption. There are lots of potential applications for networks from using predictive modelling (i.e. establishing a baseline for assessing measures designed to promote energy efficiency or flexibility; or predict consumption level in response to extreme weather conditions).
- Clustering analysis performed by Frontier Economics allows for grouping customers who do not necessarily share demographic characteristics but had similar consumption patterns which could help DNOs identify different 'archetypes' of consumption patterns, and then consider how the consumption of these groups may change in the future. This is particularly important in response to increased electrification in the home and with warmer summers having an impact on electricity consumption with air conditioning use. This type of clustering could also assist with anonymising smart meter data.

Vulnerability prediction model

- Models to detect households in vulnerable situations need to be validated using the smart meter data from the households with known vulnerability. It was not possible to perform validation during the course of the project due to data protection. This meant it was not possible to gain a detailed understanding of the underlying changes in behaviour that results in differences in energy consumption which is necessary to distinguish changes relating to becoming vulnerable from other changes that can take place in a household e.g. a change in the number of occupants, an occupant changing jobs etc.
- The use of a probabilistic model of smart meter data for the purposes of predicting vulnerability was supported, given the complex and transient nature of vulnerability. However, more granular smart meter data is required to identify vulnerabilities reliant on specialists' appliances.
- Data gathered from smart meters should be considered in conjunction with other sources of available information, such as account history and known household characteristics. Many of the household characteristics required for accurate modelling are not held by DNOs and are not freely available, therefore the costs of data provision need to be included in the cost benefit assessment. Triangulation is likely to improve the quality of predictions relating to vulnerability, and crucially, smart meter data seems likely to be capable of providing incremental utility to the accuracy of that prediction.
- The impact of vulnerability is likely to vary greatly across households and time, and certain vulnerabilities may be more detectable than others.
- The results of the cost-benefit modelling indicate that an accurate, reliable vulnerability identification model is very likely to provide a positive net present social value (NPSV). However, the extent of this will depend on the choice of algorithms and decisions on how to prioritise NPSV or benefit-cost-ratio, as well as the incentives provided to increase Priority Service Register spending.

Net-Zero carbon future scenarios for community

- Multiple plausible energy system futures exist, as does the possibility of not reaching Net Zero at all. By using the NG FES and DFES, we sought to use publicly available, robust and frequently updated scenarios that enabled replicability and cross-comparison at different levels of scale. However, feedback received during the production of scenarios revealed limitations and inappropriate underlying assumptions of these approaches to the community in question (e.g. assumptions around carbon sequestration, estimates of renewable update, behavioural change and demand reduction).

- Change is systemic, and which pathway is realised will be influenced by a huge number of interconnected technological, economic, behavioural and political factors. These factors can align to support decarbonisation, but they can also align to frustrate decarbonisation. Failing to upgrade buildings will mean Net Zero targets are missed. It will be possible to address decarbonisation – to an extent - without addressing vulnerabilities. However, progress towards decarbonisation will be frustrated if we fail to obtain a broad social mandate for Net Zero, and/or existing vulnerabilities are neglected.

Community led business model

- From the assessment work around community business cases, a support gap was identified with regards to vulnerable customers being able to access trustworthy information and grants that could help them to improve the energy efficiency of their home and take up low carbon technologies. Typically for most of these schemes once the household has been deemed as eligible, they then need to obtain an up to date Energy Performance Certificate (EPC) costing upwards of £60, plus they (or their landlord) may also need to make a contribution to the cost of installation. For some, this is unaffordable and therefore are unable to access this much needed support.

- Pseudo microgrid: The advantage gained from a pseudo microgrid is strongly linked to the capacity and type of renewable energy connected. More local generation results in more advantage to the community.

- With sufficient renewable energy generation on a pseudo microgrid, a significant energy cost saving is achieved in the ‘do nothing’ action group. This action might represent the fuel poor within the community over the next 10 years or more.

10. The Outcomes of the Project

The outcomes of the project are summarised below:

The impact of the pandemic on domestic electricity consumption:

- We found three types of customers. One group did not change consumption at any point during the pandemic and carried on with pre-pandemic consumption patterns. This was approximately a third of the sample. The second group changed consumption during the pandemic but reverted back to pre-pandemic consumption by the end of the period considered. This was approximately a quarter of the sample. The remaining customers changed consumption during the pandemic and did not fully revert back to pre-pandemic. The majority of these customers persistently increased daytime consumption, with a minority of this sub-group of customers persistently increasing peak consumption.

- We found the overall demand and consumption increases to have a relatively minor effect on bills and were not necessarily widespread across customers. Therefore the impact on fuel poverty was small and dwarfed by the impact of the subsequent Cost of Living Crisis. We found that there was not a widespread impact on the network. The majority of areas would not be pushed into constraint as a result of the pandemic effect. However there were a small number of areas where this might be the case (areas where the networks was already close to capacity, and there are significant proportions of people working from home). NGED could investigate these areas further to determine if its forecasting assumptions (e.g. within DFES) should be revisited.The full report of this stream of work is available here.

- We found that, similar to the impact of the pandemic, there were significant changes in consumption across customers. There was a large reduction in gas and electricity consumption during the three month period in our study. The reduction in consumption was larger and more variable in gas (14%) compared to electricity (8%), but it was still a large change for both.

- We found that the impact of increasing bills meant that the proportion of our sample in fuel poverty increased from 12.5% to 15.7%. This increase could have been even higher if it weren't for households taking actions to reduce consumption. This has two implications. First is that there are likely to be many households on the edge of fuel poverty that may not receive support as a result of actions they are taking themselves to ensure they do not fall into fuel poverty. Second it shows that actions can be effective in saving on household bills, but it might come at a cost of heating the home.

- The aggregate changes in consumption mask the fact that some households did a lot to change their consumption and some did very little. For electricity around a quarter of households reduce consumption by more than 20% while there are also a similar proportion of households who did not change their behaviour, consuming around the levels that would have been predicted. The variation in response is a clear signal that different households have different levels of energy price sensitivity.

- While almost all household groups saw an increase in the number of households in fuel poverty, households with elderly people saw the biggest increase as over 35% more households fell into fuel poverty. This reflects the fact that households with elderly people made smaller reductions in consumption than average. Extra provisions may be required for these households.

Vulnerability prediction model:

- A website was developed to demonstrate how the vulnerability detection model could be used in practice: https://venice.fnc.digital . The dashboard presents the smart meter data from ten real homes. The user can investigate the usage for each household and compare between the houses. This allows the user to investigate the natural variations between time-of-day and type of household.
- The results of the research undertaken by behavioural scientists to determine how customers in vulnerable situations may interact with their electricity differently is published here. The report covers the full methodology, findings, and conclusions of the behavioural science elements of the project, which were used to support data scientists in developing a model to identify vulnerability.
- Findings from the development of three separate models to identify if a household has a range different vulnerabilities has been produced and available here.

Net Zero carbon future scenarios for community:

- Methodology for communities developing local net zero scenarios was produced and is available here. The methodology can be replicated in whole, but there is also lots of potential for communities to use the document to consider the potential interactions between energy and vulnerability.
- Community scale Net Zero community carbon accounting method (available here) and accompanying carbon tool is developed to help communities explore pathways to reach net zero futures. The tool is available here.
- A guide has been written to assist community groups interested in planning for Net Zero to help any community to make the transition to a low carbon future and make sure that the most vulnerable members of the community are supported during this process. The guide is available here.

Community led business model:

- A report summarising a community led business propositions and community owned initiatives that could be used by any local community is available here.
- A strategy to reduce consumer energy costs with an innovative heat pump tariff and peak avoidance strategies was considered and available here.

11. Data Access Details

The data generated through this project is available on the VENICE Innovation webpage: www.nationalgrid.co.uk/innovation/projects/vulnerability-and-energy-networks-identification-and-consumption-evaluation-venice or directly clicking the web links provided throughout this report.

12. Foreground IPR

NGED possess full foreground IPR for all outputs produced by Frontier Economics and Frazier Nash Consultancy, i.e. all outputs concerning the assessment of COVID impact; cost of living crisis and vulnerability detection models.

WREN hold full IPR for:

- Methodology for communities developing Net Zero community future scenarios, and
- Community scale Net Zero community carbon accounting method.

13. Planned Implementation

The results of the COVID-19 persistence analysis have shown that the impact of the pandemic on domestic electricity consumption was minimal and won't persist in the future (with the exception of two groups). This confirmed that there is no need to change our existing demand forecasting methodology as the result of the pandemic.

The Cost of Living Crisis analysis identified the groups of customers that significantly reduced their consumption due to sharp increase in electricity and gas tariffs and what consumption reduction methods they adopted. The analysis also confirmed that such a quick increase in prices leads to more people pushed into fuel poverty (increase by 5% in our sample to 15.7%). The result of this work now allows NGED to focus outreach on groups likely to be in fuel-poor households by providing energy-saving advice through trusted partners.

Three independent vulnerability detection models were developed as follows: 1) Appliance disaggregation and prediction model; 2) Cohort comparison model; and 3) Overall change in usage model. None of the three models have been validated using real households with known vulnerabilities due to the restrictions in place which limit smart meter data access to DNOs and the public. Therefore, due to this lack of validation and realistic training data, currently, none of these models are ready to be deployed or used by DNOs. Further consideration will be given into how to obtain required smart meter data for validation; and also assessment performed whether follow-on work is required to finalise and integrate the models into business as usual.

All resources produced through Work Stream 3 and referenced in this report are available on NGED website to provide ongoing support to local energy groups with their ambition to achieve Net Zero. Information is shared regularly through NGED's Community Engagement forums and other external events.

14. Contact

Further details on this project can be made available from the following points of contact:

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15. Glossary

Abbreviation	Term
CEE	Centre for Energy Equality
CEP	Community Energy Plus
DFES	Distribution Future Energy Scenarios
DNO	Distribution Network Operator
DUoS	Distribution Use of System
EPC	Energy Performance Certificate
ESCO	Energy Service Company
EV	Electric Vehicle
FES	Future Energy Scenarios
GHG	Greenhouse Gas
NZcom	Net Zero Communities
LSOA	Lower Layer Super Output Area
NG	National Grid
NGED	National Grid Electricity Distribution
NIA	Network Innovation Allowance
NPSV	Net Present Social Value
PSR	Priority Service Register
ToU	Time of Use (tariff)
VENICE	Vulnerability and Energy Networks Identification and Consumption Evaluation