Review of published energy scenarios and associated methodologies

NZCom Work Package 2: Milestone 2.1

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Draft	I. Soutar	31/08/21	
Final	I. Soutar	21/09/21	1. NZCom logo amended 2. Table 3.1 amended to provide detail of project objectives 3. Additional scenarios reviewed: Zero2050 and CAT Zero Carbon Britain

Contents

Abbreviations

CAT	Centre for Alternative Technology
CCS	Carbon Capture and Storage
CSE	Centre for Sustainable Energy
DFES	Distribution Future Energy Scenarios
DIMPSA	Distributional Impacts Model for Policy and Strategic Analysis
ENW	Electricity North West
FES	Future Energy Scenarios
GSP	Grid Supply Point
NIA	Network Innovation Allowance
NZCom	Net Zero Communities
PAZCO	Pathways to a Zero Carbon Oxfordshire
SPEN	Scottish Power Energy Networks
SSEN	Scottish and Southern Electricity Networks
STSc	Socio-technical Scenarios
ToU	Time of Use tariff
UKPN	UK Power Networks
WPD	Western Power Distribution
WWU	Wales & West Utilities
ZCB	Zero Carbon Britain

1 Introduction

1.1 Background

Project VENICE (Vulnerability and Energy Networks, Identification and Consumption Evaluation) is a WPD programme funded under the 2020 Network Innovation Allowance (NIA) call 'Energy Transition: Leaving no one behind'. This comprises three related projects, one of which is the Net Zero Communities (NZCom) project.

NZCom is looking to better understand how the needs of WPD's vulnerable customers (domestic and non-domestic) will change in the future, creating novel ways to support a whole community through the transition to net zero, and understand the role community energy groups can play.

WP2 of NZCom is specifically concerned with the development of future scenarios for Wadebridge. By articulating qualitative narratives of potential energy futures, these scenarios will articulate the context to a set of 'solutions', i.e. combinations of technologies and business models, developed within WP4 and WP5. Additionally, the degree to which such solutions are aligned with net zero will be quantified by carbon accounting undertaken in WP3.

1.2 Purpose of this document

This working paper summarises key energy scenario analyses undertaken in the UK and reflects upon their relevance for scenario development in NZCom. This work therefore provides a foundation for the development of NZCom scenarios, and situates NZCom scenario development in the context of other existing scenarios.

This report is structured as follows…

Section 2 provides some background to the concept of scenarios discusses some of the most common approaches to scenario development.

Section 3 presents a review of scenario analyses, focusing on background/rationales, scenario frameworks, approaches, summary findings and accessibility.

Section 4 sets out a proposed approach for scenario development for NZCom.

2 Scenarios in energy system analysis

Uncertainties in across a large number of dimensions, including technological trajectories, policy and regulatory environments, industry ecosystems, and the nature and extent of societal engagement mean that energy systems can unfold in any number of different ways, affecting the speed and shape of trajectories towards net zero and other public interest outcomes. Decision making amid such uncertainty is challenging, particularly when decisions are costly, i.e. when they concern investments or affect the strategic direction of organisations. Energy scenarios have become recognised as useful tools for actors in industry, policymaking, energy networks and civil society interesting in understanding and shaping energy futures. This section introduces the concept of scenarios and discusses common approaches to scenario development.

2.1 What are scenarios?

Broadly speaking, scenario planning can be thought of as "systematic methods for thinking creatively about dynamic, complex and uncertain futures, and identifying strategies to prepare for a range of possible outcomes" (1). Scenarios thus provide *structure* to the analysis and management of uncertainties inherent in energy transitions.

Importantly, scenarios are not forecasts, but rather are alternative futures that are intended to 'bound' an essentially infinite range of future possibilities. While forecasts tend to provide narrow - often optimistic - perspectives on how systems will evolve, the purpose of scenarios is to develop a set of plausible perspectives that are sufficiently broad so as guide decision-making in the context of uncertainty (2).

Wright et al (3) suggest that scenario development can be helpful in:

- **Enhancing understanding** of the causal processes, connections and logics underlying events - understanding how energy futures might unfold
- **Challenging conventional thinking** – reframing perceptions and changing mindsets within organisations; reconsidering the standard assumption of business as usual
- **Improving decision-making** within organisations – Giving organisations/managers direction/confidence amid uncertainty by informing strategy development (or stress-testing pre-determined strategies)[1]

While scenarios are generally used to discuss a range of possible futures, many scenario exercises (particularly those of relevance to the current study[2]) are inherently 'normative' or goal-oriented, focusing for example on reaching sustainability goals such as net zero. While such normativity is natural (and indeed should be acknowledged), it is important not to develop scenarios that are: overly optimistic, for example uncritically adopting assumptions about the role of specific technologies such as CCS or nuclear (4); nor too pessimistic, for example expecting technological diffusion to move only as slow as historical transitions.

Scenarios can be understood as tools for constructing 'energy futures', i.e. anticipatory discourses and techniques for visualising and elaborate the future (5). However, since these energy futures are subjective, reflecting specific views about the role of technologies, infrastructures, society and policy, it is important to remain critical of the rationales, methods and assumptions embedded within the development of scenarios.

In general, to be of value to decision makers, scenarios need to be[3]:

- **Plausible**: Depict credible futures built on logical assumptions of how change unfolds
- **Consistent**: Internally coherent, with mutually compatible assumptions
- **Relevant**: Detailed enough to be of use for the intended audience

In addition, scenario sets need to be of a manageable number (i.e. typically four or fewer) to allow decision makers to relate to them in a systematic way (6).

[1] Wright et al (2013) argue that while scenarios are often useful for enhancing an organisation's understanding and challenging conventional thinking, whether or not scenarios support decision-making depends is largely subjective

[2] Alongside normative approaches (how to reach a target), scenarios may also be exploratory (what *can* happen?) or predictive (what *will* happen?) (63).

[3] From van der Heijden et al 2009, Hoolohan et al 2019

2.2 Approaches to scenario development

While multiple methodological approaches to scenario development exist, two approaches are particularly relevant here. The *Intuitive Logics* approach focuses on identifying the driving forces, or critical uncertainties that are thought to shape future business environments, consideration of the plausible outcomes of these forces, and understanding how these forces interact with one another (3,7). A final set of four scenarios are defined by the most extreme outcomes of two clusters of uncertainties, identified by a ranking exercise. The *Intuitive Logic* approach has found traction among energy system analysts within, for example, National Grid (see Section 4.1), the IPCC, the World Economic Forum (8) and Shell (9,10).

While a key strength of the Intuitive Logics approach is to reduce a vast number of futures to a more manageable set of three or four scenarios, the approach consequently struggles to deal with systems in which there are abundant sources of uncertainty, where nonlinearity/discontinuity results in unpredictable outcomes. In other words, the Intuitive Logics approach is relatively blind to 'surprise futures'. This is particularly problematic if scenarios are being developed with the express purpose of managing surprises.

An alternative, the so-called *Morphological Approach*, seeks to overcome this limitation by allowing for the identification of more than two critical uncertainties affecting change, thus broadening the problem space (11,12). Rather than boiling a large set of uncertainties down to two clusters, the Morphological Approach allows scenarios to be defined by multiple parameters deemed to have an impact on futures. To broaden perspectives on change, such approaches often seek to engage a wider diversity of participants than is common with an Intuitive Logics approach. However, since there are more combinations of variables to consider, this approach is thought to be more demanding of participants than an Intuitive logics approach (2).

2.3 Integrating quantitative and qualitative analysis

Scenarios typically comprise combination of quantitative and qualitative analysis. Quantitative analysis in the form of modelling is useful in simulating changes to key, measurable aspects of energy systems within reasonable timeframes. Insights derived from quantitative models alone are limited, particularly if there are long time horizons and the system of interest is complex. As such, narrative scenarios are frequently generated in which qualitative factors (e.g. political, institutional, behavioural), are emphasised to complement and enrich quantitative modelling (13).

While most efforts in scenario development comprise blends of quantitative and qualitative analysis, it is important to consider how these strands are integrated. McDowall (14) identifies three key approaches. The first articulates (in qualitative terms) broad trends (in politics, culture, economics etc.) which are then used to develop qualitative models. This approach is aligned to the Intuitive Logics approach outlined previously. The second approach involves detailed quantification of narrative scenarios, with model outputs then communicated back to stakeholders.

While these approaches are commonplace among analysts, they assume that a) qualitative factors are exogenous to trends and that b) quantitative model outputs are robust enough to guide decisions. A third approach – a so called Sociotechnical Scenarios (STSc) approach avoids the integration of models and qualitative narratives per se, but uses both strands recursively. This approach focuses on creating a dialogue between models and qualitative storylines, acknowledging that both strands have strengths and weaknesses (4).

3 Summary of scenario analyses

This section together a range of projects in which energy system scenarios have been developed and which hold relevance for NZCom. These cover national scenarios as well as efforts to develop scenarios for regional and local areas. A summary of reviewed scenarios is given in Table 3.1[4].

Table 3.1. Summary of reviewed energy system scenarios

Geography	Project	Lead partner (reference)	Area of focus	Focus/framing of scenarios
National	Future Energy Scenarios (FES) 2021	National Grid ESO (15)	GB	Technological and societal changes needed to meet net zero by 2050.
	Zero Carbon Britain (ZCB)	CAT (16)	UK	Technically plausible scenario for meeting net zero by 2030
Regional	WPD Distribution Future Energy Scenarios (DFES) 2020	Regen (17)	South West England	Technological and societal changes needed to meet net zero by 2050 (aligns with FES 2020)
	Net Zero South Wales 2050 (NZSW)	Regen (18)	South Wales	Impact of heat decarbonisation trajectories on electricity and gas networks (aligns with FES 2019/20)
	Zero2050 South Wales	NG (19)	South Wales	Optimisation of technological mixes to meet net zero by 2050
	Pathways to a Zero Carbon Oxfordshire (PAZCO)	ECI (20)	Oxfordshire	Technological and societal changes needed to meet net zero by 2050 (aligns with FES 2020)
	4D Heat	SSEN (21)	Scotland / Isle of Skye	Technological and behavioural options for flexible electrified heat in absorbing otherwise curtailed wind generation, and analysis of associated reduction in emissions.
Local	Green City Vision	WWU (22)	Swindon	Analysis of feasibility and disruption of different heat trajectories aligned with (80%) emissions reduction targets
	Communiheat	OVESCO (23)	Barcombe	Impact of planned versus unplanned heat transition on networks
Other relevant projects	Smart and Fair	CSE (24)	n/a	Distributional impacts of shift to smart energy system, defined by technologies and behavioural changes identified by FES 2019.
	Distributional impact of UK climate change policies	CSE & ACE (25)	n/a	Cost recovery options for meeting (15%) emissions targets
	An Electric Heat Pathway	SSEN (26)	n/a	Role of electric storage and hot water tanks in existing heat decarbonisation scenarios

This review is not exhaustive; rather, the focus here is on those pieces of work that are of most relevance to the current study. At the national level, National Grid's most recent Future Energy Scenarios (FES 2021) is the latest in an established set of GB scenarios. These are widely regarded as robust and are used extensively across industry and policymakers. They have also been used by other projects to ensure that regional/local scenarios are aligned with national views.

[4] A long list of other studies also included Project Synthesis (SPEN), Smart Hooky (WPD) and CEA (CSE), although these do not engage explicitly with scenario development and so were deemed out of scope.

Also at the national level (UK rather than GB) is CAT's Zero Carbon Britain scenario, which in contrast to FES focuses on a single desirable scenario, and on net zero by 2030 rather than 2050.

At the regional level, Distribution Network Operators (DNOs) all individually produce Distribution Future Energy Scenarios (DFESs), including SPEN (27), SSEN (28), ENW (29), Northern Powergrid (30), UKPN (31). However, since these all take similar approaches to scenario development, WPD's DFES for their South West network area is of particular relevance for NZCom scenarios, and it is that particular DFES that is discussed in depth in Section 3.

Also at a regional level are scenario exercises undertaken by SSEN focusing on minimising wind power constraints in Scotland (4D Heat), and the University of Oxford's Environmental Change Institute's (ECI) PAZCO project focusing on zero carbon pathways in Oxfordshire.

At a more local/community level are WWU's Green City Vision and OVESCO's CommuniHeat projects, focusing respectively on Swindon and Barcombe.

Finally, three further relevant studies are flagged as being of particular relevance/interest to NZCom in considering the incorporation of vulnerabilities in energy scenarios.

The focus of this review is on understanding the rationales, approach and methodologies behind published scenario exercises with a view to informing scenario development in NZCom, rather than the findings of scenario exercises.

3.1 FES 2021

3.1.1 Background

National Grid ESO have been publishing Future Energy Scenarios (FES) annually since 2011. These represented a shift away from single forecasts for electricity and gas demand published by NG in their annual electricity and gas Ten Year Statements. Future energy scenarios are used for a number of regulated activities including informing network investment, system operability and security of supply. The most recent set of scenarios was published in July 2021.

FES scenarios are GB-wide. They thus consider changes to both transmission and distribution networks, and take into account (where possible) regional variations. The Distribution Future Energy Scenarios (DFES) developed by DNOs provide more granular projections incorporate bottom-up data on changes to distribution networks.

3.1.2 Framework

FES scenarios follow an intuitive logics approach in which an agreed scenario framework defines the problem space by differentiating between individual scenarios. Scenario frameworks are shaped by consultations with stakeholders about which trends are likely to influence energy system change. As such, the NG FES scenario framework has evolved over the last decade to consider the interaction between different sets of factors (Figure 3.1). Evolution of the framework over time can be understood in relation to technological trends and shifts in the political and economic environment, reflecting for example the energy 'trilemma' framing (2014-2017), political and financial uncertainty brought on by Brexit (2017), and most recently, the net zero agenda (2020-2021)[5].

[5] FES 2021 also includes analysis on the impact from COVID-19 on energy demand and economic growth, and notes that FES 2022 will further reflect observations of post-lockdown impacts.

Figure 3.1. Uncertainty axes in NG FES scenario frameworks

Based on the agreed framework, narratives based on political, economic, social and technological factors are articulated for each scenario across multiple modelling areas (energy demand, electricity demand, gas and heat demand, generation, gas supply, hydrogen, flexibility, transport and support mechanisms). These narratives provide qualitative 'uncertainty envelopes' within which different technologies play a greater or lesser role. Scenarios are differentiated quantitatively by varying assumptions and 'levers', i.e. the quantitative attributes used as modelling inputs.

The FES 2020 (32) represented a change in framework to better align with the UK Government's net zero commitments adopted in 2019. Key changes to the FES 2020 framework as compared to the 2019 framework include:

- A shift away from the focus on 80 per cent decarbonisation target[6] used in FES 2019 (albeit with net zero sensitivity analysis) towards a net zero target.
- The introduction of 'level of societal change' to replace 'level of decentralisation' as a key determinant of change for energy futures. This echoes the explicit attention given to the importance of societal and behavioural change in the Climate Change Committee's Net Zero report (33) and Sixth Carbon Budget Scenarios (34).
- Distinct heat technologies being employed in each scenario rather than in combination. This reflects two distinct logics (supply side versus demand side) with which low carbon heat can be delivered.

3.1.3 Approach

FES 2021 draws on a combination of established and bespoke bottom up and top-down models, bringing together multiple energy components to give a whole system view of energy system change (Figure 3.2) (35). Key models/modules include:

- **End consumer demand**, comprising electricity demand, gas demand, industrial and commercial demand, residential demand, and road transport demand
- A **whole system view**, incorporating whole system demand, electricity supply, natural gas supply, bioenergy supply and hydrogen supply
- **Flexibility**, covering Residential Demand Side Response (DSR), Industrial and commercial DSR, Vehicle-to-Grid, Electricity peaks, Hydrogen production

Figure 3.2. NG's general approach FES modelling

[6] Based on the Climate Change Act 2008 target

Regional energy demand is projected to regional areas by mapping gross demand (demand as metered at the transmission network plus demand from non-transmission connected generating assets) at the GB level onto individual GSPs. BEIS data on domestic and non-domestic demand at Middle Super Output Areas (MSOA) is used to calculate a percentage split of domestic and non-domestic demand in each GSP

Scenarios are aligned with net zero objectives by integrating FES assumptions with the bottom-up UK TIMES Model[7]. This finds least cost solutions at a whole system basis to meeting net zero

3.1.4 Scenarios

FES 2021 comprises four scenarios (Figures 3.3 & 3.4). These are distinguished by their position on two axes: 1) speed of decarbonisation and 2) societal change. Two FES2021 scenarios – Consumer Transformation and System Transformation represent mid-level trajectories towards net zero. This is bookended with a faster scenario – Leading the Way, which reaches net zero by 2047, and Steady Progression, which fails to reach net zero by 2050 altogether. The mid-level scenarios are differentiated by a variation in societal engagement; the System Transformation scenario relies on system-level changes to heating infrastructure, supply side flexibility, whereas the Consumer Transformation scenario relies on broad and deep societal engagement in the adoption of electrified heating technologies, behaviour change and demand-side flexibility.

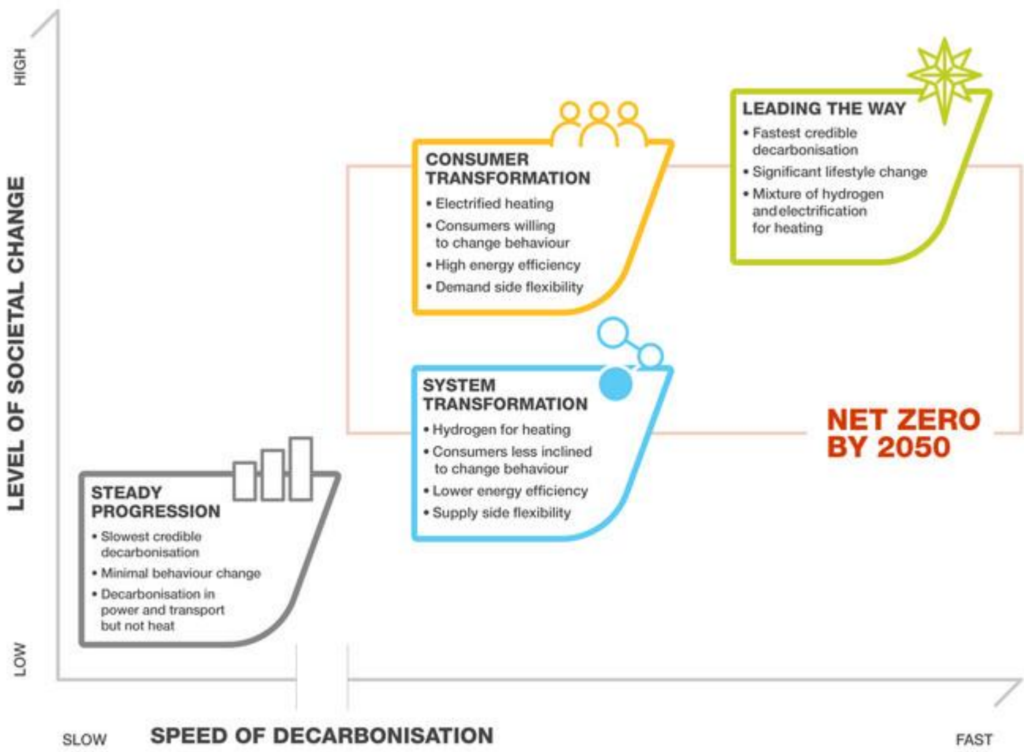

Figure 3.3. NG FES Framework and scenarios

[7] The UK Times Model and its predecessor, UK MARKAL, also underpin the CCC's carbon budget analysis

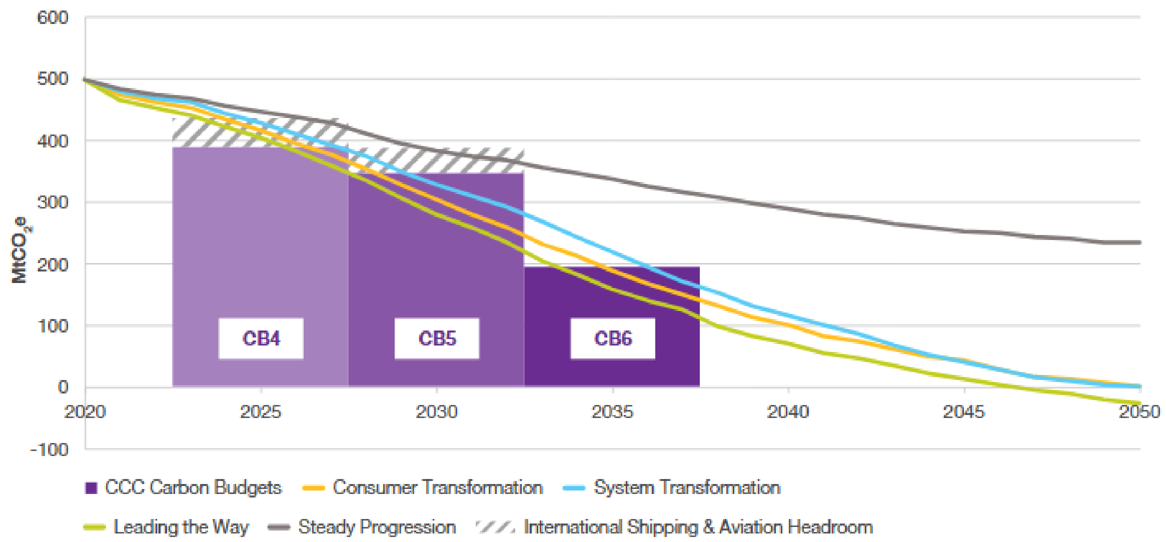

Figure 3.4. Total net greenhouse gas emissions and carbon budgets under FES 2021 scenarios

While the National Grid scenarios were originally developed to guide decision-making at the national level, efforts have been made as part of the ENA Open Networks project to align these with the development of distribution network scenarios. The National Grid FES 2010 data workbook (36) thus includes a set of common 'Building Blocks', which disaggregate supply/demand from different technologies down to the level of GSP. This allows for alignment of national FES projections and regionally-specific DFESs. This includes annual projections for generation from specific technologies, demand from domestic, industrial and commercial, heat and transport, demand from low carbon technologies, and uptake of storage and flexibility technologies and services.

3.1.5 Resources

Assumptions and levers used in FES 2021 are provided in Excel format at GB (36) and regional levels (37). This includes demand, supply and flexibility at GB level and for regional building blocks. Interactive maps of regional breakdowns are also available (38).

Carbon emissions are provided at an aggregate level for grid-connected generation only, and are not broken into contributions from individual technologies.

3.2 Zero Carbon Britain

3.2.1 Background

The 2019 Zero Carbon Britain (ZCB) publication (16) is the latest in a series of reports from the Centre for Alternative Technology (CAT) which each set out single possible scenarios for the UK reaching net zero by 2030. As such, the chief aim of the ZCB 2019 scenario is to set out what a low carbon world could look like, and highlight the role of existing (rather than future) technologies in meeting net zero ambitions.

3.2.2 Approach

As a starting point for scenario development, CAT place several constraints on future energy systems based on the author's value judgements and perceptions of what net zero ought to represent. Namely; electricity is 100% renewable, with nuclear component in 2030; immature or otherwise risky geoengineering options are ruled out, and prioritisation of those options with the highest public support; no fossil fuel power coupled with CCS; and no international imports of electricity or other energy sources.

Rather than focusing on the trajectory for achieving net zero over time, the ZCB scenario represents a technically plausible snapshot of the energy system in 2030, from 2017 as a base year. To illustrate the potential disparity between the scenario and carbon budgets, the report proposes a linear reduction in emissions to 2030 (Figure 3.5) although the authors do highlight that changes to infrastructure will likely change the shape of this trajectory.

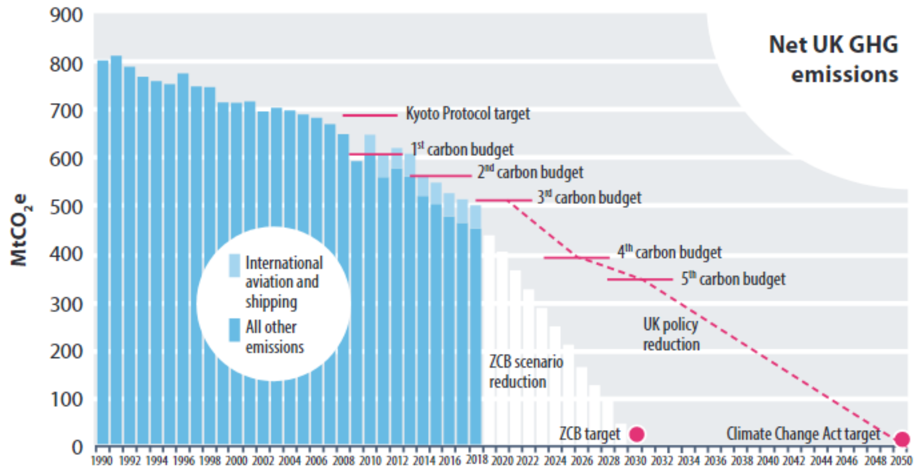

Figure 3.5. Transition to net zero under ZCB 2019 scenario

Analysis encompasses all components of carbon emissions, including energy (buildings, transport and electricity), non-energy (e.g. industrial processes, infrastructural leakage, urban expansion, and waste) and land-use (agriculture, biomass and carbon sequestration). Carbon is counted on the basis of production rather than consumption, with the assumption that emissions associated with goods imported to the UK are also reduced.

Behind the ZCB scenario is a ten-year hourly energy model showing how energy demand for transport, industry, services and electricity can be met from variable renewables, backed up by carbon neutral synthetic gas (sustainably produced biomass combined with hydrogen from electrolysis). This uses hourly weather data (sunlight, wind speeds, temperatures) from the ten years to 2022 to test future renewable energy mixes under real life conditions (39).

3.2.3 Scenarios

The ZCB scenario suggests that 60% reduction in overall energy demand (“Powering down”) is possible, with particularly large savings in heating buildings (50%) and transport (78%). At the same time, it is suggested that demand could be completely decarbonised by 2030 (“Powering up”) without the use of nuclear, with wind playing a central role (Figure 3.6).

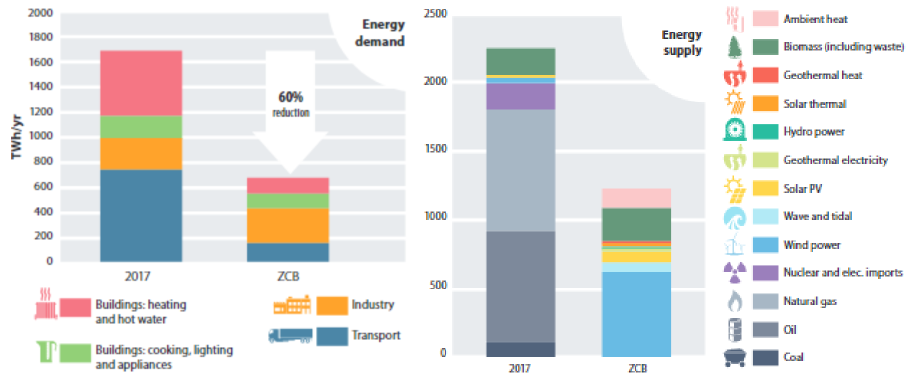

Figure 3.6. Total energy demand by sector and energy mix under the ZCB scenario

While the focal point of ZCB is a single scenario, CAT highlights that this should be considered a starting point for conversation rather than the only way to proceed, and outlines a number of theoretical variations to the central scenario (40). These variations include more or less ambitious demand reduction measures, multiple heating and transport solutions, high battery storage capacity, complete removal of biomass from scenarios, and different nuclear scenarios.

3.2.4 Resources

Alongside the main summary report (41), methodology papers provide data and assumptions used to develop the scenarios (42). The ZeroCarbonBritain hourly energy model (43) allows for manipulation of input variables and visualisation of outputs for exploration of other scenarios.

3.3 WPD DFES 2020

3.3.1 Background

WPD, along with many other DNOs, produce scenarios for electricity distribution network areas - Distribution Future Energy Scenarios (DFES). WPD – in collaboration with Regen - has produced DFES for its network areas in a two-year cycle since 2015, and is due to continue on an annual basis. This has until recently been a proactive process in that there have been no regulatory requirements for DNOs to produce scenarios (44)[8]. As with the NG FES more generally though, WPD DFES is designed to a) identify least regret investment options, b) identify opportunities for non-network solutions and flexibility, c) manage network uncertainty, d) future proof investment and e) supporting strategic investment (45). The most recent WPD DFES was published in November 2020 (46)[9].

DFES are granular projections for changes to generation, demand and storage technologies on distribution networks. WPD undertake DFES for its four license areas - one of which is South West England (Figure 3.7).

[8] As part of RIIO-ED2, DNOs will be required to produce scenarios in consultation with stakeholders, written in a consistent manner, be auditable, and for data to be fully available.
[9] Summary reports for WPD's four license areas will be published at the end of 2021.

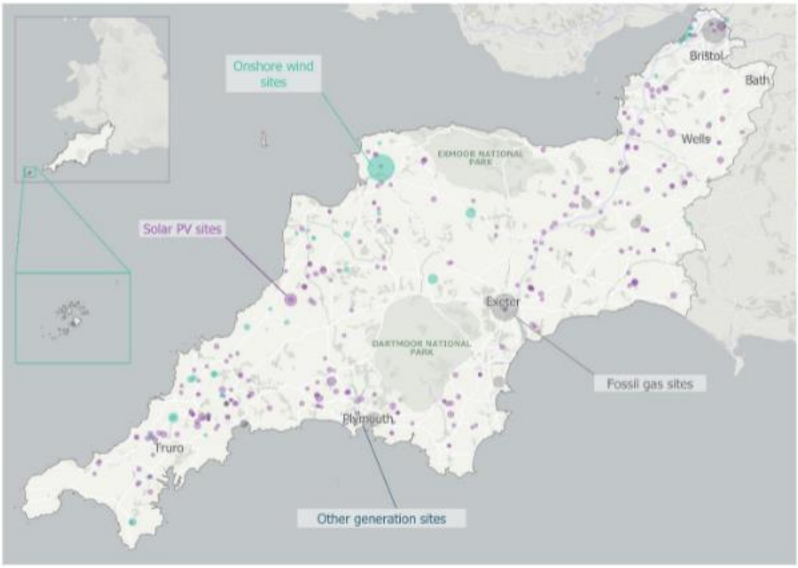

Figure 3.7. WPD's South West license area

3.3.2 Framework

As with other DFESs produced by other DNOs, DFES adopts the NG FES scenario framework. WPD DFES 2020 aligns with the four FES 2020 framework scenarios (i.e. those defined by speed of decarbonisation and level of societal change).

3.3.3 Approach

WPD DFES comprises a bottom-up analysis of changes on the distribution network at a regional and sub-regional level, reconciled with FES 'building block' projections (46). As such, modelling is restricted to providing local context to the assumptions set out in FES. The WPD DFES 2020 is reported at both Electricity Supply Area (ESA)[10] and Local Authority level, and are reconciled to FES 2020 results "as far as possible", although some variance between DFES and FES views are expected (46).

A baseline is created from WPD connection data, subsidy registers, Department for Transport data and other national datasets to analyse spatial trends within license areas. Pipeline analysis is then carried out to build a picture of supply trajectories (to include sites with connection offers or with active planning applications) and changes to demand (to include prospective domestic and non-domestic property developments) within the network area. DFES projections thus seek to provide a more accurate view of regional developments from granular knowledge about resource availability, historic factors, political factors, pipeline factors and uptake rates. Input from local stakeholders (renewable developers, local authority planners[11] and others) thus forms an important part of the analysis.

[10] ESAs are defined as the 'geographical area supplied by a Primary Substation (which contains WPD-owned distribution substations) providing supplies at a voltage below 33 kV, or a customer directly supplied at 132, 66 or 33 kV or by a dedicated Primary Substation

[11] While housing and population projections remain consistent across FES scenarios, they interact with DFES scenarios by increasing demand for electricity and heat, but also increase the uptake of new technologies such as electric vehicles, heat pumps and rooftop solar PV.

3.3.4 Scenarios

The WPD DFES 2020 scenarios adopt the FES 2020 scenario framework – four scenarios differing by speed of decarbonisation and level of societal change. DFES scenarios focus on projections for technologies connected to the distribution network. An indicative set of projections for Cornwall is shown in Figure 3.8.

Technology	Units	Baseline Total	2030				2050			
			SP	ST	CT	LW	SP	ST	CT	LW
Air conditioning	Number of domestic air conditioning units	2777	11341	9412	9412	3023	192650	107943	107943	3508
Direct electric heating	Number of customers with direct electric heating	21936	23099	22867	22715	23054	26104	22701	21658	23382
Domestic	Number of new dwellings	0	10793	14240	14240	18636	32077	45282	45282	64314
Electric vehicles	Number of electric vehicles	2929	49152	64422	108610	127401	396940	383830	354769	270785
EV Charge Point	Number of EV charge points	1242	17792	25092	57135	63651	148710	155083	157065	160483
Heat pumps	Number of heat pumps	7417	10741	33423	83718	92605	82765	129155	223413	220779
Non domestic	Floorspace (metres squared) of new I&C developments	0.0	180139.0	246140.0	246140.0	327902.0	582849.0	624157.0	624157.0	556153.0
Other Distributed Generation	MW (installed capacity)	122.3	186.6	135.4	175.9	164.7	246.3	125.9	252.7	217.4
Solar Generation	MW (installed capacity)	533.6	642.3	727.5	835.3	841.1	896.5	1504.0	2006.1	1887.2
Storage	MW (installed capacity)	0.0	23.6	13.0	48.4	62.6	83.6	43.3	217.9	267.0
Wind	MW (installed capacity)	152.6	171.7	210.7	307.5	267.5	221.7	321.9	834.1	627.1

Figure 3.8. DFES 2020 technology projections across scenarios for Cornwall[12]

Since DFES scenarios align with FES scenarios, they do not include analysis of carbon emissions nor of the impact of technologies on the ability to provide flexibility services (45)[13]. Rather, DFES scenarios take FES 2020 building blocks as a starting point, which are disaggregated to GSP level. As such the more granular technology projections developed under DFES scenarios may mean that the carbon impact of scenarios does not fully align with FES scenarios. For example, more displacement of natural gas by higher uptake of heat pumps in a local area will – all other things being equal - reduce the carbon intensity of that area.

3.3.5 Resources

As well as providing high-level summary of scenarios in regional reviews (47), WPD DFES also includes reports on local assumptions for the South West license area (46) as well as interactive maps of technology projections at both ESA and Local Authority levels (48). Results of local stakeholder consultations are also published (49).

3.4 Net Zero South Wales

3.4.1 Background

Net Zero South Wales 2050 (NZSW) was an Ofgem-funded Network Innovation Allowance project undertaken by Regen, Western Power Distribution (WPD) and Wales and West Utilities (WWU). This

[12] Alongside the four DFES scenarios is a fifth 'Best View' scenario created by WPD for the purpose of regulatory reporting. This aligns with one of the four scenarios WPD deems most likely to play out, based on regional ambitions and delivery capabilities. Leading the Way represents WPD's Best View scenario for DFES 2020

[13] WPD DFES 2020 does not in itself include analysis of loads, peak loads and constraints - this is carried out separately through WPD's Shaping Sub-transmission process

was a one-off project carried out in early 2020, with a focus on developing insights about integrating gas with electricity scenario planning for an increasingly flexible and cross-vector system (18). The project had two main objectives: 1) to create integrated distribution future energy scenarios (DFES) for both gas and electricity networks and 2) to develop a methodology for the development of cross-vector scenarios at a regional level (50).

NZSW focused on bringing together scenarios for WPD's South Wales and WWU's South Wales network areas (Figure 3.9).

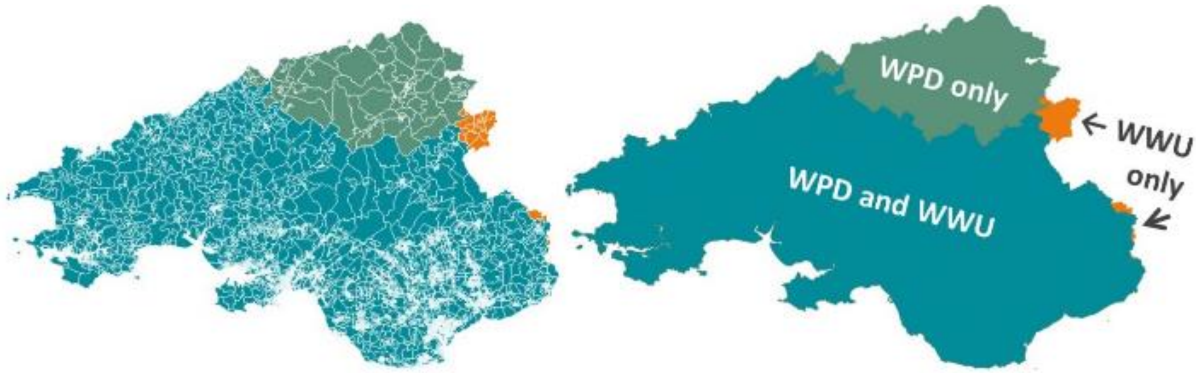

Figure 3.9. Overlap between WPD and WWU license areas. Source: (50)

3.4.2 Framework

A key driver for the NZSW project the need to understand the impact of different trajectories for decarbonising heat on the partners' network areas. As such, the scenario framework is defined by heat decarbonisation either being delivered primarily by electrification via heat pumps, resistive heating or low carbon heat networks (High Electrification), conversion of the gas grid to transport hydrogen (High Hydrogen) and a hybrid scenario comprising conversion of gas grid for urban areas alongside electrification and biomethane (Core Hydrogen) (Figure 3.10). While not aligning directly with FES scenarios, NZSW scenarios envisage heat trajectories similar to those in FES 2019 and 2020 scenarios.

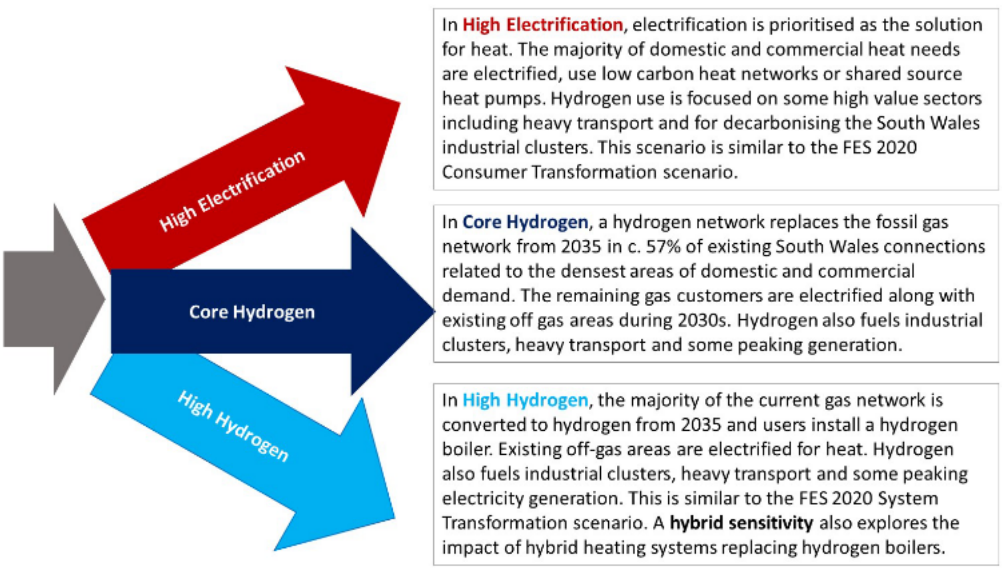

Figure 3.10. High level net zero scenario narratives for NZSW

3.4.3 Approach

NZSW used a similar approach to WPD DFES 2020 to develop scenarios – a bottom up analysis incorporating short and long-term projections of gas and electricity projects alongside planning information from local authorities, and a long-term set of net zero sensitivity projections[14] (Figure 3.11). This was then used to generate network impacts in terms of representative and peak days, energy profiles, and network forecasting for combined electricity and gas networks. Analysis suggested a role for peak shifting although this was not modelled.

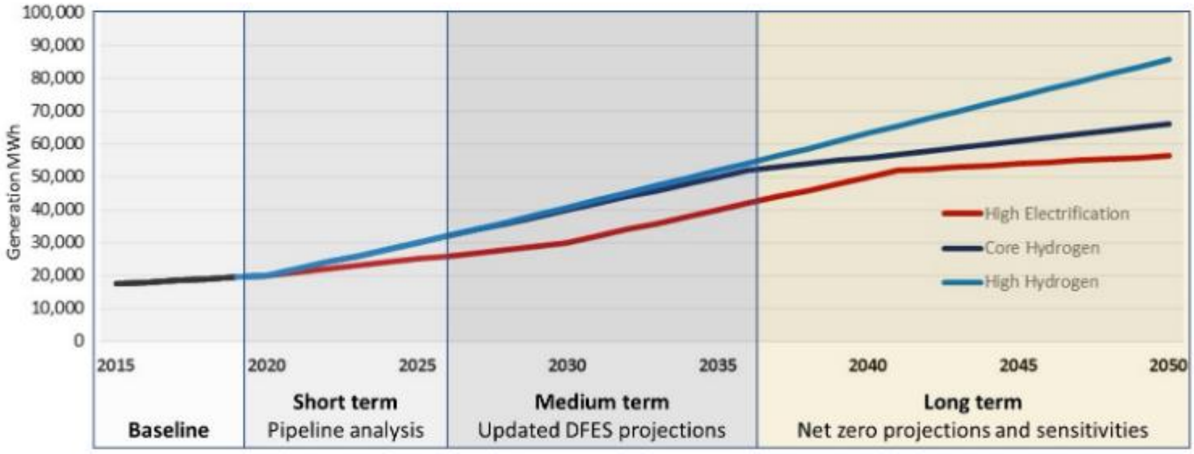

Figure 3.11. Illustration of NZSW net zero scenarios methodology

3.4.4 Scenarios

NZSW's three different scenarios reach net zero by 2050 (Figure 3.12). All scenarios assume replacement of methane for heating with combinations of heat pumps, hydrogen and biomethane injection of gas network. The High Electrification scenario results in the lowest energy use overall, reflecting efficiencies of heat pumps and more efficient buildings.

[14] NZSW was carried out prior to FES 2020, so adopted the net zero sensitivity analysis used in FES 2019. This stretches the assumptions of FES 2019 scenarios from meeting 80% emissions reductions to 96% from 1990 levels and 100% utilising additional (as yet commercially unproven) technologies.

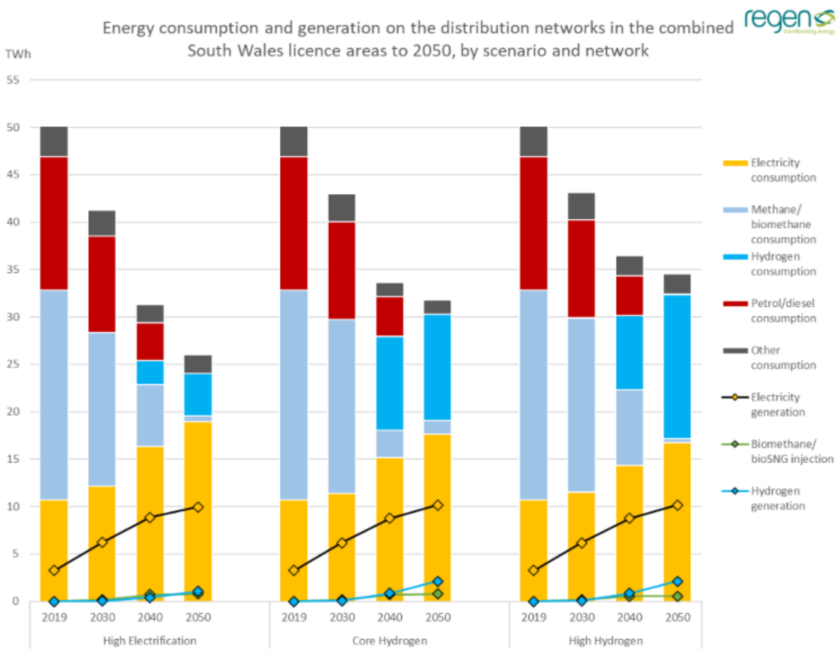

Figure 3.12. Distribution network energy demand and supply by NZSW scenario

3.4.5 Resources

A data companion report (50), learning report (51) and Excel dataset (52) for the NZSW project are all available via the WPD website.

3.5 Zero2050

3.5.1 Background

The Zero2050 project (19) is a NIA funded project led by National Grid Electricity Transmission and involving a number of other partners, including utilities, industry, academia, SMEs, consultants, Government, and others. The project ran from November 2019 to July 2021. The focus of Zero2050 was to develop a blueprint for decarbonisation in South Wales, with the stated aims of:

- Identifying up to four plausible decarbonisation scenarios to net zero;
- Collate the evidence required to underpin decision making around net zero, including an understanding of the impacts (and uncertainties thereof) of the pathways across the energy system and on wider society
- Testing methodologies for collaborative decarbonisation at a system level across a region.

These outputs are designed to inform investment decisions for electricity and gas grid operators, policy choices for the Welsh Government and Local Authorities, and investment options for local businesses.

3.5.2 Approach

Zero2050 brought together analysis on multiple parts of the energy system to provide a whole system perspective on optimal energy pathways for South Wales. An optimisation work package brought together outputs from all other work packages. This used the open source energy systems modelling Calliope[15] tool, which takes inputted demand profiles, existing technology capacities and

[15] https://www.callio.pe/

theoretical upper limits, transmission links and existing capacities, and technological costs and operational inputs, and provides an optimised mix of energy generation technologies and their capacities for dispatch based (53).

Modelling was undertaken using Calliope for the years 2030, 2040 and 2050, with outputs from the 2050 model run used to feed a 2040 model run – and again for a 2030 model run - for each of the socio-economic scenarios. The 2050 model run was optimised to net zero. The cost and carbon implications of the system on a yearly basis is then generated, and indicative pathways are calculated by interpolation. The relationship between work packages and this final optimisation process is illustrated in Figure 3.13.

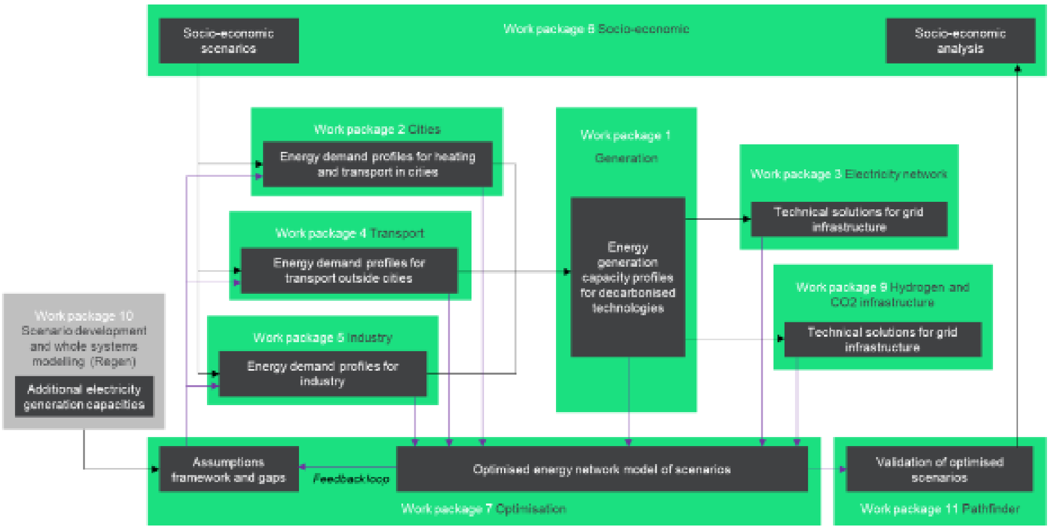

Figure 3.13. Zero2050 work flow

3.5.3 Scenarios

The Zero2050 project incorporates scenario analyses across multiple work packages. This included:

- Three socio-economic scenarios (Current Trends, Green Industrial Growth, and Service Led Growth) as a contextual framework in which plausible decarbonisation pathways are situated. These scenarios primarily differ in terms of changes to demand profiles across industrial, commercial and transport sectors (54).
- Two heat decarbonisation scenarios (Electrification and Hydrogen)
- Two scenarios for decarbonisation of transport (High Growth and Low Growth). The High Growth scenario aligns with the Green Industrial Growth and Service Led Growth scenarios in the overarching project, while the Low Growth scenario aligns with the Current Trend scenario (55).
- Three plausible scenarios for decarbonisation of heavy industry by 2050 (High Electric, High Hydrogen and a ‘plausible’ Clean Growth scenario (56).

Optimum energy demand and supply mixes for 2030, 2040 and 2050 were generated for a high electrification scenario, indicating increased capacity and supply from both ground-mounted PV and offshore wind (Figure 3.14).

Modelling of socio-economic scenarios indicate that while some scenarios emphasise specific technological trajectories, some technologies (onshore wind and solar, maximisation of electricity from EfW and landfill, heating dominated by heat pumps, ramping up of ‘green’ hydrogen production, and hydrogen storage) are consistent across all scenarios – and thus represent 'low-regret' actions (Figure 3.15).

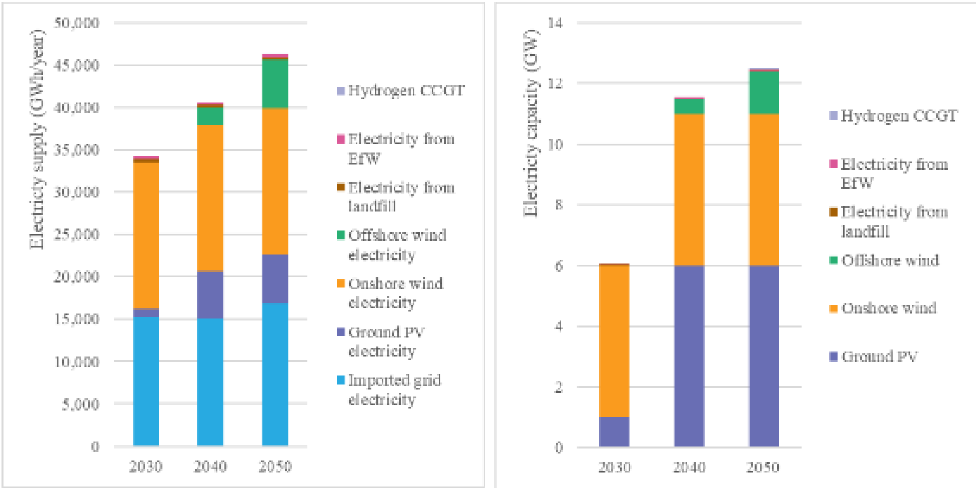

Figure 3.14. Electricity supply generation (L) and plant capacity (R) for high electrification scenario

Consistent across all cases	Green industrial growth	Current trends	Service led growth
Onshore wind and ground PV play a major role in electrical generation	Lots of offshore wind	No offshore wind	Some offshore wind
All scenarios maximise electricity from EfW and landfill			
Heating is dominated by heat pumps	More biomass boilers and GSHPs	More ASHPs	More ASHPs
In 2030, 50% of hydrogen produced by electrolyser. By 2050 all hydrogen produced by electrolyser.			
Hydrogen storage in tanks and caverns	More hydrogen storage in 2050, 60% in caverns	40% of hydrogen storage in caverns, lower storage requirements	40% of hydrogen storage in caverns, lower storage requirements

Figure 3.15. Summary of findings under Zero2050's socio-economic scenarios

Additional modelling was also carried out to test the sensitivity of the Green Industrial Growth scenario in 2050 under specific constraints (e.g. no wind for 5 days, or electricity demand being met solely by local generation). As with the socio-economic scenarios, several technological trajectories that are consistent across all cases can be identified as low-regret actions – several of which have parallels with those identified by way of the socio-economic scenario modelling runs. (Figure 3.16).

Consistent across all cases	Sensitivity 1: Heat dominated by electricity	Sensitivity 2: Heat dominated by hydrogen	Sensitivity 3: Limit hydrogen storage capacity	Sensitivity 4: No wind for 5 days	Sensitivity 5: Islanding
Lots of offshore, onshore wind and ground PV		More imported electricity		More imported electricity	No imported or exported electricity
Electricity from landfill and EfW	Electricity from hydrogen CCGT	Electricity from biomass and sewage gas		Electricity from hydrogen OCGT	Electricity from biomass and sewage gas, anaerobic digestion and hydrogen CCGT
Hydrogen production by electrolysis		Hydrogen imported and exported			Hydrogen imported and exported
ASHPs and GSHPs maximised		Less HPs because hydrogen dominates			
Hydrogen storage in caverns and tanks			Linepack only available for hydrogen here	Batteries are used	Large amount of energy storage as hydrogen storage in caverns
A small amount of biomass for heating		More biomass heating	More biomass heating	More biomass heating	More biomass heating

Figure 3.16. Consistency and difference across sensitivities tested in Zero2050

3.5.4 Resources

The project approach, interactions between work packages and modelling assumptions are detailed within a series of work package reports (19).

3.6 Pathways to a Zero Carbon Oxfordshire

3.6.1 Background

The 'Pathways to a Zero Carbon Oxfordshire' (PAZCO) report (20) was created by the University of Oxford's Environmental Change Institute (ECI) in collaboration with Bioregional, and supported by the Oxfordshire Local Enterprise Partnership (OxLEP). The study builds on a 2014 ECI report which proposed scenarios for low carbon economic growth in Oxfordshire (57).

3.6.2 Approaches

The 2021 report developed new scenarios to align with the new context of net zero. To do so, it adopts the FES 2020 scenario framework also used by SSEN to produce DFES scenarios. FES 2020 data on energy demand, renewable generation and EV uptake is used as a starting point, and assumptions around population growth and housing were adjusted, and the petrol/diesel ban date was updated to reflect the most recent government policy. Scenarios focus on two milestones – 2030 and 2050 – to align with a local interim target of 50% reduction in emissions, and the national net zero target.

Analysis encompasses energy supply, transport, buildings, land use and carbon sequestration, but not food production or consumption. Given that Oxfordshire does not have a major airport nor heavy industry, a decision was made to set a target for 'zero carbon' (rather than net zero) without relying "more than absolutely necessary" on negative emissions.

3.6.3 Scenarios

Apart from the Steady Progression scenario (which fails to meet the net zero target), PAZCO scenarios are named to distinguish them from the FES 2020 scenarios on which they are based. Thus, Societal Transformation, Technological Transformation and Oxfordshire Leading the Way align with net zero compliant pathways varying in terms of level of societal engagement and speed of decarbonisation.

The report articulates scenarios in terms of technologies, behaviours and policy environments, and, based on FES 2020 regional building blocks, quantifies progress against a set of indicators of relevance for Buildings (Figure 3.17), Heat, Transport, Electricity Supply, Flexibility and Land Use).

Scenarios	Steady Progression		Societal Transformation		Technological Transformation		Oxfordshire Leading the Way		Notes
Indicator	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	
Buildings									
No. of pre-2020 homes renovated	3,000	30,000	8,900	280,000	3,000	150,000	8,900	280,000	Supply chains and governance arrangements will take 5–10 years, so little change before 2030.[56]
Energy standard for retrofits, kWh/m^2/year (useful energy; domestic space heating only)	100	100	100	60	100	100	100	60	
Average EPC rating for all buildings	D	D	D	B	D	C	D	B	Current average is D; improvement requires support to achieve higher ratings and a regulatory minimum standard to make low-rated buildings unusable (with finance and other support for upgrades).
Percentage of Oxfordshire businesses conducting annual carbon footprints and/or energy audits	3%	6%	15%	80%	10%	40%	20%	80%	Figures refer to businesses with employees (excludes sole traders)
Proportion of large businesses with published net-zero strategies	5%	30%	60%	95%	30%	60%	70%	100%	
Coverage of business networks dedicated to achieving zero-carbon (% of total number of businesses)	3%	10%	20%	40%	5%	15%	25%	50%	Examples include Zero Carbon Oxford Partnership and Oxfordshire Greentech, but more are needed. Figures exclude sole traders.
Heat									
Natural Gas demand (GWh)	4,800	4,900	3,600	0	4,300	0	3,300	0	Demand in 2018 was 5,270 MWh
Hydrogen demand (GWh)	20	160	19	1,600	110	5,300	30	1,800	Currently negligible.
Number of heat pumps (total installations)	41,000	190,000	120,000	390,000	64,000	250,000	130,000	390,000	There are roughly 1,500–2,000 heat pumps in Oxfordshire currently.

Figure 3.17. Progress towards selected indicators in the Pathways to a Zero Carbon Oxford scenarios

In addition, technological trajectories are presented visually for a range of indicators (e.g. Figure 3.18).

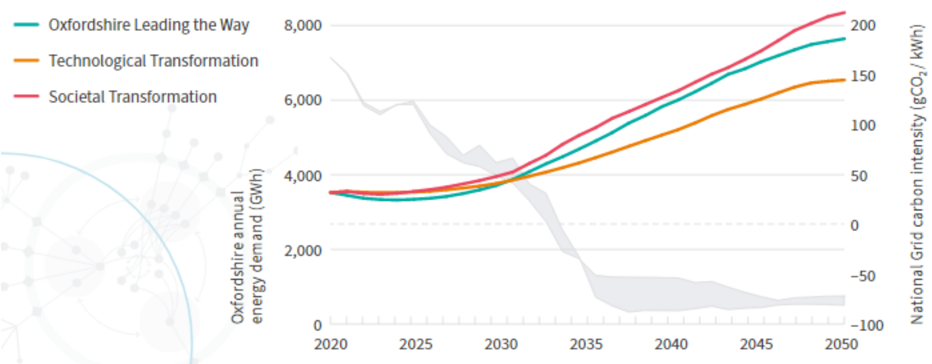

Figure 3.18. Annual electricity demand across Zero Carbon Oxford scenarios

As well as illustrating potential pathways to meet zero carbon ambitions, the PAZCO report highlights several features in common across all scenarios. These include substantial growth in solar PV, building retrofits, stricter approaches to planning and building regulations, and phase out of gas boilers, among others.

The report also highlights the variety of economic, social and environmental co-benefits of zero carbon transitions. These vary across scenarios. Technological Transformation scenario is least disruptive (allowing for private vehicles, low retrofit rates and conversion to hydrogen boilers). Meanwhile, the Societal Transformation and Oxfordshire Leading the Way scenarios require most societal engagement, although it is noted that the capacity to engage in such behaviours is not evenly distributed.

3.7 4D Heat

3.7.1 Background

4D Heat (21) was a six month NIA project carried out in 2020, led by Scottish and Southern Electricity Networks (SSEN) and National Grid ESO with research, modelling and analysis carried out by Delta-EE, Everoze and PassivSystems. The project's stated focus was on understanding the potential for domestic heat to address all four challenges of decarbonisation, decentralisation, digitisation and democratisation inherent in the shift to a net zero future. Specifically, 4D Heat explored the ability of flexible electrified heat to absorb wind generation that would otherwise be curtailed due to England-Scotland transmission constraints, and the key drivers for achieving this (21).

The Isle of Skye was identified as a representative off-gas grid community within the SSEN license area, although the results were linearly scaled-up to reflect heating loads of all off-gas grid homes in Scotland.

3.7.2 Approach

To answer 4D Heat's core question of "what is the maximum volume of wind energy that the ESO could avoid having to curtail by incentivising electric residential heating turn-up at times of wind curtailment?", the project: sought to:

1. Analyse how well DSO and ESO constraints match with the available flexibility from electric heating loads;
2. Conduct a cost benefit analysis (CBA) to identify if a domestic turn-up service is a cost effective and scalable solution, and;
3. Evaluate consumer perspectives and potential routes to market.

3.7.3 Scenarios

Scenario modelling was used to understand how curtailment could be minimised without impacting adversely on the distribution grid, or home comfort. Scenarios differed in terms of uptake of domestic technologies, ESO markets (offering homes a financial incentive to increase demand at times of curtailment) and energy supply markets (adoption of dynamic Time of Use (ToU)) tariffs reflecting the wholesale electricity price plus variable Distribution Use of System (DUoS) charges) (21).

Two base modelling years – 2020 and 2030 - allowed changes in wind generation and housing stock to be investigated, with the latter aligning with the FES 2019 Two Degrees scenario[16]. Additional assumptions for 2030 included improved insulation levels, an increase in heat electrification, and the removal of the Radio Teleswitch Service (RTS)[17]. Five scenarios for each base year were modelled (Figure 3.19).

[16] The FES 2019 Two Degrees scenario aligns with a 80% emissions reduction target by 2050

[17] Due to be decommissioned by 31 March 2023.

Scenario	Building stock & wind curtailment profile		RTS homes present	Main electric heating technology	Smart controls installed	Explicit wind consumption incentivised	Dynamic ToU tariffs used
	2020	2030					
A1: 2020 Base case	✓		✓	Storage heaters			
B1: Smart controls only (RTS)	✓		✓	Storage heaters	✓		
C1: Optimisation to ESO wind constraints (RTS)	✓		✓	Storage heaters	✓	✓	
B2: Smart controls only	✓			Storage heaters	✓		
C2: Optimisation to ESO wind constraints	✓			Storage heaters	✓	✓	
D: 2030 Base case		✓		Heat pumps			
E: Smart controls only		✓		Heat pumps	✓		
F: Dynamic ToU tariff		✓		Heat pumps	✓		✓
G: Optimisation to ESO wind constraints		✓		Heat pumps	✓	✓	
H: Dynamic ToU tariff + Optimisation to ESO wind constraints		✓		Heat pumps	✓	✓	✓

Figure 3.19 4D Heat scenarios

Six house archetypes were identified, based on 2011 census data and local EPC data. Energy consumption for each archetype was based on real world data from PassivSystems technology. Changes in space/water heating technologies in homes in 2030 are assumed to have been made, affecting demand for space and water heating, as well as non-heating electrical demand (Figure 3.20).

Archetype	2030 heating system	Hot water heating type	Improvements to Insulation	Number of occupants	Space heat demand (kWh)	Hot water demand (kWh)	Non-heating electrical demand (kWh)
Detached bungalow 1	ASHP	From main system	Loft in all homes applicable (~30%) and solid wall insulation	1	9,629	1,788	1,731
Detached bungalow 2	Fossil fuel, boiler and radiators	From main system	Loft in all homes applicable (~30%)	2	17,497	2,526	4,603
Semi-detached bungalow	Electric storage heating	Electric immersion, off peak tariff	Loft in all homes applicable (~30%)	1	10,113	1,788	1,731
Detached house 1	ASHP	From main system	Loft in all homes applicable (~30%) and solid wall insulation	2	10,766	2,526	3,541
Detached house 2	Fossil fuel, boiler and radiators	From main system	Loft in all homes applicable (~30%)	4	20,412	4,001	6,336
Semi-detached house	Electric storage heating	Electric immersion, off peak tariff	Loft in all homes applicable (~30%)	2	13,189	2,526	4,603

Figure 3.20. 4D Heat 2030 House archetypes and changes made in relation to 2020 houses

4D Heat modelled electricity demand for space and water heating across 3589 off-grid homes, which then allowed for modelling of system cost reduction from matching wind curtailment with domestic heating flexibility across the various technology/tariff scenarios. This sought to join up micro-level analysis of heat demand for specific property types with macro-level analysis of network implications. Cost Benefit Analysis was used to scale up modelling on Skye to cover all of off-grid gas Scotland across each scenario. This included the costs of smart control options. The costs of installing heat pumps and insulation were assumed to be implemented across all scenarios so were not included in the analysis.

3.7.4 Scenario outputs

4D Heat project highlights a role for heat flexibility – provided by smart controls, ToU tariffs and direct wind curtailment incentives in reducing curtailment costs. ToU tariffs indirectly incentivise the use of otherwise curtailed wind based on low wholesale price periods, whereas direct wind curtailment provide direct incentives, accessed through smart controls, to households to increase demand at times of wind curtailment. Combinations of flexibility options help to reduce wind curtailment and maximise cost benefits at the system level (Figure 3.21).

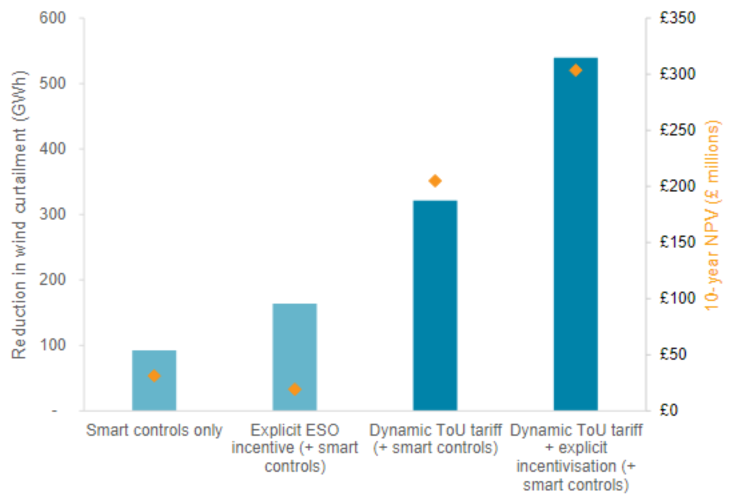

Figure 3.21. Reduction in wind curtailment and 10-year NVP under 4D Heat scenarios

3.7.5 Resources

Methods and assumptions for 4D Heat are published in a final project report (21).

3.8 Green City Vision

3.8.1 Background

Green City Vision (22) was a NIA funded project carried out between 2018-19 by WWU, UKPN, SSEN and Progressive Energy. The overall aim was to develop a better understanding of decarbonisation across increasingly integrated gas and electricity systems. Analysis focused on developing an optimum, feasible solution for decarbonisation of gas and electricity within the Swindon area.

3.8.2 Approach

Green City Vision used WWU's Energy Pathfinder model (58) to understand how electricity and gas networks would operate under defined scenarios. Pathfinder can be used to assess the feasibility of different energy mixes in terms of cost, carbon impact, reliability and shortfall/surplus in heat and power supply (and thus storage needs), and can thus be used to determine how electricity and gas networks would operate under a user-defined scenario for specific target periods.

Projected carbon emissions for 2050 for the Swindon area were based on carrying through the proportion of the region's emissions related to the UK in the period 2005-2014 (77% of the UK's average) through to 2050.

3.8.3 Scenarios

Green City Vision scenarios were based on a status quo 'reference case' derived from FES 2018 data with scenarios representing decarbonisation trajectories away from this reference case. Scenarios are distinguished by different heat technology trajectories (electrification and hybrid heat pumps, versus biomethane and hydrogen blending), actors involved (businesses versus domestic consumers), and decarbonisation logics ('supply' driven versus 'demand'), and combinations thereof. 'Supply-driven' in these scenarios relate to modification of demand side technologies, while 'demand-driven' relates to installation of energy efficient appliances paired with behavioural/lifestyle changes in homes, and adoption of CHPs, electrification of LGVs and CNG conversion of HGVs.

All scenarios are designed to comply with the FES 2018 emissions reduction target (80% emissions reductions from 1990 across power generation, commercial heat and power, road transport and domestic heating). All scenarios also assume a minimum of 19% home efficiency gains and 90% EV adoption in the reference case. This resulted in the generation of eight scenarios (Figure 3.22).

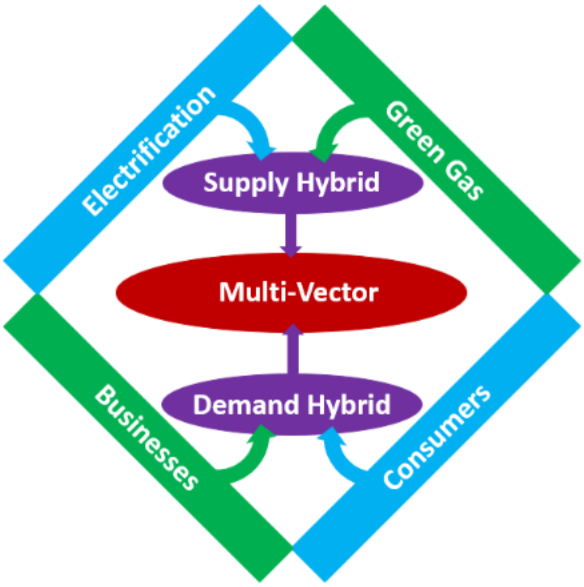

Figure 3.22. Green City Vision conceptual compliance map

Green City Vision takes a top-down approach whereby necessary reductions (driven by the emissions reduction target) to gas and electricity demand are calculated. This informs necessary investments in electricity and low carbon gas capacity (hydrogen blended or hybrid systems) on the supply side, and associated behavioural changes on the demand side – across each scenario (Figure 3.23).

Strategy	Scenario	Description
N/A	Reference	Baselining a possible 'status-quo' of the SN area in 2050, based on 2018 National Grid FES.
Supply-Driven	Electrification	Achieving compliance by solely leveraging low-carbon electricity use.
Supply-Driven	Green Gas	Achieving compliance by solely leveraging low-carbon gas use.
Supply-Driven	Supply-Hybrid	Achieving compliance by balancing the deployment of low-carbon electricity and low-carbon gas, minimising disruptive impact where possible.
Demand-Driven	Consumer Led	Achieving compliance by consumers taking full ownership via modifying behaviour and personal investment.
Demand-Driven	Business Led	Achieving compliance by businesses taking full ownership via modifying behaviour and investment.
Demand-Driven	Demand-Hybrid	Achieving compliance by balancing the modification of consumer and business behaviour as well as investment, minimising disruptive impact where possible.
Combined Supply and Demand-Driven	Multi-Vector	Achieving compliance by balancing supply-driven and demand-driven approaches, maximising low-regrets solutions and highlighting engineering trade-offs.

Compliance Strategy	Technology Investment	Lifestyle Changes
Electrification	60,000 ASHP conversions + 40,000 hybrid installations + 100% adoption of EVs	Adoption of Time of use Tariff (optimise electricity use) + Heating use expectations change due to ASHPs
Green Gas	No technology investment for biomethane + hydrogen blending, or 100% gas boiler replacement for hydrogen conversion	No lifestyle changes
Supply-Hybrid	Between 60,000 – 90,000 ASHP installations (based on stand-alone vs hybrid) + 100% adoption of EVs	Adoption of Time of use Tariff (optimise electricity use) + Heating use expectations change due to ASHPs
Consumer Led	Increase home efficiency gains to 28% technical limit + Installation of energy efficient appliances + 100% adoption of EVs	Adoption of Time of use Tariff (optimise electricity use) + Reduction of home temperatures to between 12 – 15 °C
Business Led	CHP investments + 100% electrification of LGVs + 100% HGV CNG conversion	Energy use reduction of 45% for both gas and electricity
Demand-Hybrid	Increased home efficiency gains to 23.5% + 95% electrification of personal transport and LGVs + 50% HGV CNG conversion	Adoption of Time of use Tariff (optimise electricity use) + Energy use reduction of 25% for both gas and electricity for all consumers + Reduction of home temperatures to between 14 – 16 °C
Multi-Vector	58,000 hybrid installations + 100% adoption of EVs (cars and vans) + Conversion to CNG HGVs + Increased CHP usage	Adoption of Time of use Tariff (optimise electricity use) + Reduction of home temperature to 17 °C + Heating use expectations change due to ASHPs

Figure 3.23. Green City Vision scenarios and compliance strategies

WWU's analysis suggests that low carbon gas, supported by efficiency improvements and hybrid heat pumps, is regarded as the 'least disruptive' decarbonisation strategy in requiring 'no lifestyle changes', and necessitating continued operation of gas and electricity networks. Top-down 'supply' strategies (e.g. investment in biomethane plants) were regarded as be more deliverable than demand-side approaches, which were regarded as comparatively disruptive in terms of implications for household investments and necessary behavioural changes.

3.8.4 Resources

The final project report, including methodology and assumptions are available (22).

3.9 CommuniHeat

3.9.1 Background

Communiheat (23) is a NIA-funded project running from 2020-June 2022. The project is a partnership between the community of Barcombe in East Sussex, Ovesco, Buro Happold and UK Power Networks (UKPN). The project was initiated to develop a roadmap for Barcombe and other off-gas grid communities to move to low carbon heating in an achievable, affordable, inclusive and comfortable manner. One key focus for UKPN is to explore the consequences of a planned versus an unplanned heat transition on energy networks. Communiheat's ambition is for Barcombe to become the UK's first net zero village, reaching net zero by 2030.

3.9.2 Approach

CommuniHeat is taking a bottom-up approach to understand the potential for low carbon heating. Data will be collected from the installation of 50 non-invasive data loggers in homes, carrying out up to 200 domestic EPCs in the area, and Lidar data of solar incidence in the village to understand the potential for rooftop PV.

Building archetypes based on energy demand profiles provide a basis for exploring the feasibility of perusing different technological solutions – including network costs – at the community scale. These data are being used to develop a digital twin of the village to better understand which technologies are most applicable, and how community financing can help finance proposed solutions.

3.9.3 Scenarios

Scenarios are under development, although in broad terms scenarios are expected to represent the impact on the network of taking a planned versus an unplanned approach to heat decarbonisation. While an unplanned pathway would be characterised by individual households installing low carbon technologies, a planned pathway means using community assets and economies of scale to make the transition.

3.9.4 Resources

Communiheat is ongoing, so project outputs are yet to be published. Recorded webinars are available focusing on the project in general (59) and introducing Barcombe's digital twin (60). In relation to the latter, a virtual map of the village has been developed in which the impacts of various routes to heat decarbonisation – at an individual household as well as at a community level - can be simulated and visualised (Figure 3.24) (61).

Figure 3.24. Visualisation of carbon emissions in Barcombe

3.10 Other relevant projects

3.10.1 Smart and Fair

Smart and Fair (24) is a project run by the Centre for Sustainable Energy (CSE). Phase 1 ran from 2019-2020, and Phase 2 started in May 2021 and is ongoing. The main aim of Smart and Fair is to understand how a shift to a smarter energy system can generate unfairness, in terms of the distribution of system costs and benefits, and potentially leave people in terms of the complexity and costs of participation.

Phase 1 of Smart and Fair (62) developed an analytical framework to better understand the kinds of customer capabilities and attributes likely to be required to transition to a smart energy future (with a so-called Offer Profiling tool), and assessed the distribution of participation in smart energy offers and services across the population (with a so-called Consumer Classification model). While Phase 1 did not involve scenario analysis as such, it drew from published scenario work (e.g. FES 2019, UKERC 2019) to develop an overview of the range of technologies likely to play a part in transitions to smart, low carbon energy futures.

Building on this analytical framework, Phase 2 is examining the possibility of improving the functionality of the Consumer Classification model developed in Phase 1 by incorporating real-world policy or regulatory scenarios.

3.10.2 Distributional impacts of UK Climate Change Policies

This 2010 study (25), commissioned by Eaga Charitable Trust and carried out by CSE and ACE, aimed to assess the scale of sustainable energy deployment needed to meet emissions targets[18]. To do this, CSE used the 'Distributional Impacts Model for Policy and Strategic Analysis' (DIMPSA) model to understand the distributional impacts and benefits of policy delivery. DIMPSA is based on data of household energy consumption, the English House Condition Survey, and Ipsos MORI/Ofgem data on energy consumer market behaviour.

Upon determination of the scale of renewable deployment needed, and the cost thereof, the 2010 study used DIMPSA to examine three different scenarios for cost recovery through energy bills. These scenarios include:

1) a 'Spread Even' scenario, in which costs are recovered evenly across the customer base in proportion to household fuel expenditure

2) a 'Commercial Reality' scenario in which suppliers load costs on to non-switchers, with more competitive pricing offered to switchers.

3) an Income Taxation scenario in which costs are recovered through income taxation rather than energy bills.

The study concludes that cost recovery through energy bills appears more regressive than the income taxation alternative. Given that income taxation is unlikely to be politically palatable however, the study states that cost recovery through energy bills should be designed to be as fair as possible.

3.10.3 An Electric Heat Pathway

SSEN's Electric Heat Pathway project (26) was funded by SSEN as part of its Network Innovation Allowance (NIA). The key focus was to produce a report setting out the role of electric storage heating and hot water tanks in heat decarbonisation, and identifying business models for delivering these.

Rather than developing scenarios as such, the report focused on:

- Stimulating public debate around heat decarbonisation;
- Understanding the opportunities and benefits of flexible heating demand, and how best to implement them
- Providing insights to SSEN on how to tackle immediate issues relating to RTS de-commissioning with alternative commercial / regulatory models

A key finding was that while many current heat decarbonisation scenarios (e.g. those carried out by CCC, NG FES, and BEIS) explicitly focus on heat decarbonisation, they ignore the role of smart

[18] At the time 15% of 1990 levels by 2020, as defined by the EU Renewables Directive

storage heating as well as hot water requirements. It argues that while properties with storage heaters may be difficult to upgrade/decarbonise, they are often occupied by vulnerable households, meaning sidelining this segment of households risks leaving vulnerable customers behind. The report also argues that smart storage heating and hot water could potentially provide the required flexibility more readily than heat pumps, which typically feature as a key component of heat decarbonisation scenarios.

3.11 Section summary

Scenarios are of relevance to a range of actors operating across diverse organisational settings, interested in understanding and shaping energy system change across multiple scales and geographies. Scenarios – even in the small subset reviewed here - vary considerably, although these are also commonalities. This section offers some reflections on the reviewed scenarios.

Different approaches/framework. While some sets of scenarios are derived from the future contexts in which they are imagined to exist (e.g. the FES scenarios), other scenarios are defined by specific technological trajectories (e.g. Green City Vision). While the latter may be more appropriate for organisations with narrow questions in mind (e.g. is gas or electricity more likely to be used to decarbonise heat by 2050?), the former is more likely to create scenarios that open up, rather than close down, discussion about future energy systems. There are, in short, a multiplicity of understandings about what scenarios are.

Top-down versus bottom-up approaches. Most of the scenarios incorporate both top-down and bottom up analyses. Carbon constraints frequently feature as a top-down constraint, rather than determined by bottom-up quantification - although the link between technological trajectories and final carbon intensities is not always clear. Bottom-up analysis frequently focuses on households, although some (e.g. Communiheat) are also interested in understanding the agency of the community in shaping energy system change.

Alignment with net zero. Scenarios are increasingly aligned with net zero objectives. However, not all studies engage with the possibility of not reaching net zero, and the scenarios produced therein might therefore offer overoptimistic views of the future. Net zero is usually (although this is not always made explicit) taken to mean net zero across heat, electricity and transport, although the analysis in the reviewed scenarios typically focus on changes in heat and electricity. The notable exception is PAZCO, which includes land use and carbon sequestration, and focuses on 'zero-carbon' to remove reliance on negative emissions.

Scenarios are political. Scenarios represent plausible, but also desirable, energy futures. It is important to recognise that all scenario exercises incorporate biases and subjectivities about, for example, the role of specific technologies (or industries), or the acceptability of different forms of societal engagement. For example, Green City Vision's scenarios includes an 'Electrification' scenario, although this comprises both ASHPs *and* hybrid gas boilers rather than fully electric technologies. Similarly, many scenario exercises no not engage with the potential for disruption. In this regard, the 'planned' versus 'unplanned' focus adopted by Communiheat is interesting.

Societal engagement. All scenarios require societal engagement of some kind. Even those net zero scenarios presuming the lowest engagement in terms of technology adoption (e.g. FES's System Transformation) require ambitious efficiency measures.

Lack of attention to vulnerabilities. While many scenario exercises acknowledge that energy trajectories will impact upon vulnerable customers, very little attention is paid to understanding the impact of specific scenarios on these customers. Given that energy trajectories will – at least in part - be influenced by the degree to which householders can pay the costs and access the benefits of the energy transition, as well as how fairness is perceived, embedding a more complete understanding of vulnerabilities in scenario work is needed.

4 Proposed approach for NZCom

This section reflects on general criteria for scenario development, considers additional criteria of particular relevance to NZCom, and proposes a broad approach for scenario development throughout WP2. It should be noted that this section represents work in progress and the final approach will be tailored to integrate with other work packages in NZCom.

4.1 NZCom scenario criteria

Adapting the general criteria for scenario development outlined in Section 2.1, NZCom scenarios should be:

Plausible	Scenarios should depict credible energy futures for the Wadebridge & Padstow Community Network Area, based on logical assumptions of how change unfolds.
Consistent	Internally coherent, with mutually compatible assumptions - around, for example, technological trajectories, policy and regulatory environments.
Relevant	Detailed enough to be of use for the intended audience. Audiences for NZCom includes WPD but also WREN and other relevant stakeholders.

With reference to the 'Relevance' criteria, NZCom scenarios should also be:

Goal-oriented	With two objectives in mind: reaching net zero, while addressing the needs of vulnerable customers
Replicable	Scenario approaches and assumptions should be designed in a way to allow other communities to develop scenarios of their own. This means developing methods that are not dependent on specialist knowledge or analytical expertise
Local	Reflecting the specifics of the local context in terms of resources, infrastructure, demographics etc. to be able to inform local practices and strategies.
Consistent across scales	Scenarios should be aligned with scenarios already developed for use within broader geographical scales

4.2 WP2 approach

NZCom scenarios will be developed by adapting established relevant scenario frameworks to incorporate a bottom-up Intuitive Logics approach specific to NZCom. In particular, the National Grid FES 2021 scenario framework (see Section 5) will likely be used as a foundation, upon which additional critical uncertainties relating to net zero and vulnerability objectives will be overlain.

The FES process draws both on established quantitative models and extensive stakeholder engagement. It has come to represent something of an industry standard. While the scenario framework is likely to continue to evolve, it is likely to do so in unison with DFES scenarios. However, the focus on GB means it is (necessarily) broad, and could be tailored to NZCom's needs.

The NZCom scenario framework will thus combine multiple uncertainty axes relating to speed of decarbonisation and scale of societal engagement (from FES 2021) along with additional points of uncertainty of relevance to vulnerability. The latter will be identified in consultation with project partners – an initial scoping exercise has highlighted economic growth, regulatory environment, and engagement with vulnerability as key uncertainties. While many of the high-level assumptions made within FES 2021 will be adopted, this process will mean articulating new assumptions of particular relevance to the Wadebridge and Padstow network area.

While building on the established methods developed by National Grid, this approach allows for the integration of local challenges and solutions, and also for the co-production of local scenarios by local stakeholders. Co-producing scenarios with local stakeholders means they are a) more likely to reflect local views about energy system change and b) more likely to be of practical use to decision-makers.

NZCom narrative scenarios will be aligned with modelling by taking a STSc approach to provide a dialogue between scenario storylines and energy flow and carbon models (Figure 4.1). This will allow models and narrative scenarios to be developed concurrently, each iterating with respect to each other recursively.

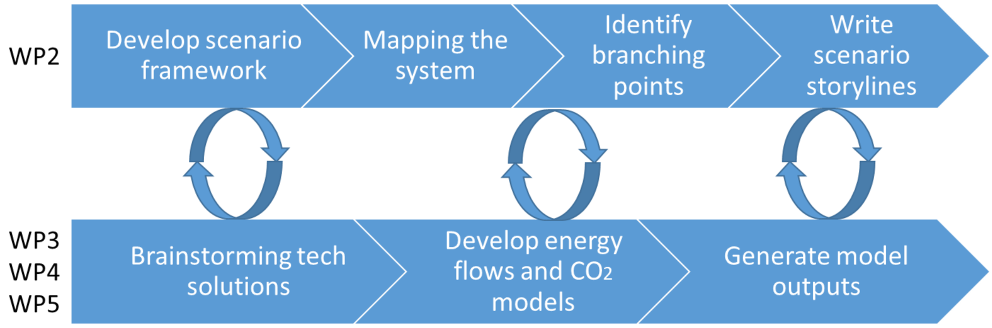

Figure 4.1. Interaction of narrative scenarios with energy flows and carbon modelling

An initial brainstorming exercise undertaken in WP3 will identify potential solutions comprising technologies and associated business models. WP2 will then map the sociotechnical systems around these proposals. This will assess the proposed innovations in relation to the wider niches in which they are developing, and the wider sociotechnical regimes in which they may become embedded.

Individual scenarios will be distinguished through the identification of 'branching points', i.e. key decisions or other tipping points that favour support specific technological pathways over others. Bridging points might include, for example, a national boiler replacement scheme accelerating uptake of heat pumps, or electricity market reform creating possibilities for network innovation.

Finally, scenario storylines will be written, incorporating the implications of key uncertainties and bridging points. This process will be carried out in collaboration with project partners and a wider set of stakeholders in a scenario workshop. Scenarios will be articulated in dialogue with model outputs by a) ensuring that the assumptions embedded in energy flow and carbon models are reflected in scenario narratives and b) ensuring that model runs reflect the dynamics of change articulated in storylines.

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