Pathways to a zero carbon Oxfordshire

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Abstract

Climate mitigation is a global problem whose solution involves local delivery. The need for coordinated interventions at multiple scales is widely acknowledged, but is hard to achieve in practice. Political commitment through declarations of 'climate emergencies' needs to be reflected in action on the ground. Local governments are well placed to convene partnerships, but resources are scarce and the task of scaling up is often hindered by national policy. This paper records the research commissioned by the six relevant local authorities to map pathways to a zero-carbon economy for the county of Oxfordshire (UK). Building on an earlier report (presented at the eceee Summer Study 2015), we summarise recent progress on reducing carbon emissions, showing that Oxfordshire is on track to achieve a 50 % reduction by 2030. However, decarbonisation achievements have been uneven and we highlight the need for urgent action on transport and heat decarbonisation if this trend is to continue. We present three distinct pathways for eliminating carbon emissions in Oxfordshire, with varying levels of individual behaviour change, community leadership, and reliance on technological solutions, and contrast these with a business-as-usual scenario. Finally, we reflect on the ongoing process of engagement with representatives of local government and other stakeholders in trying to steer a path towards zero carbon.

Introduction

Tackling climate change has become an urgent priority for governments, businesses and citizens around the world. In 2019, the UK Parliament passed legislation committing to a target of net-zero carbon emissions by 2050. In response, local authorities have been scaling up their ambitions to mitigate climate change. In Oxfordshire, all local authorities have acknowledged and responded to the climate emergency, and are developing plans to achieve net-zero carbon emissions by 2050 or sooner.

This paper reflects on a recent report that we were commissioned to write, mapping pathways to a zero-carbon economy in Oxfordshire. The project had a steering group of 12 local stakeholders, including six local authorities, the local electricity network operator, and several business support organisations. The governance of this project reflects the complex landscape of local governance itself. Oxfordshire has a two-tiered local authority system. Besides Oxford City Council, there are four District Councils in Oxfordshire, which hold responsibility for waste collection and recycling, air quality and housing. The County Council sits above these, with responsibility for transport, education, waste management and social care. Both tiers have a role in land use planning. Local government politics has long been divided, with the left-of-centre Labour party controlling Oxford City for several decades, surrounded by a largely rural county run by the right-of-centre Conservative party. There are several other organisations with a key role in local governance. These include the Local Enterprise Partnership and the Oxfordshire Growth Board which focus on strategic planning, investment and economic development. These organisations collaborate with local authorities and other stakeholders (such as energy companies, government agencies, community networks) in complex ways on specific programmes

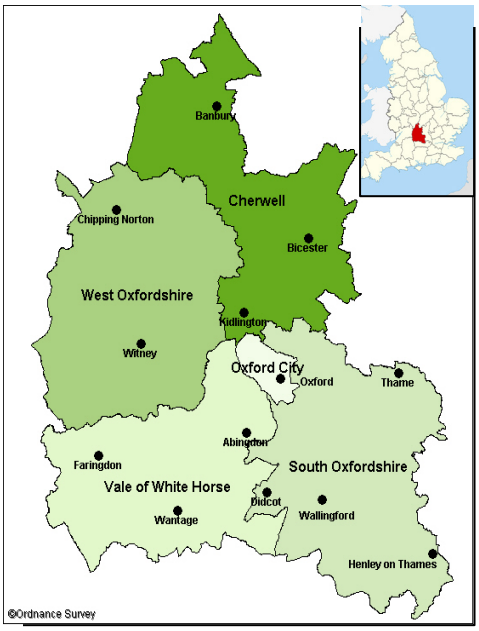

Figure 1. Oxfordshire's local government boundaries and location in the UK.

and initiatives. This model of governance is notably divergent from how regional economic development is governed in much of the EU, and has been the subject of some criticism (Britton and Woodman, 2014; National Audit Office, 2016; Johnston and Blenkinsopp, 2017).

The 2021 project builds on a report in 2014 on the status and potential of the low carbon economy in the county (Patrick et al., 2014), the findings of which were presented at the eceee Summer Study in 2015 (Killip et al., 2015). That conference paper reflected on the importance of adapting national and international climate goals into locally specific strategies for decarbonisation, as well as the need to involve a range of local stakeholders to build consensus around the need for low-carbon innovation and emissions reduction.

This paper is presented in three parts. Firstly, we provide an overview of progress made locally towards achieving climate goals. Against a baseline of 2008, Oxfordshire's local authorities have committed to reducing emissions by 50 % by 2030, and our findings show that the county is currently on track for this target. However, progress has been uneven, and there is a need for substantial action on transport and heat decarbonisation if this trend is to continue.

Secondly, we outline four future scenarios for Oxfordshire's economy out to 2050. Our scenarios are based on the 2020 UK National Grid Future Energy Scenarios (FES) with some modification to reflect Oxfordshire specific differences in technological resource and socio-demographic trends compared to the national average. The first, called *Steady Progression* extrapolates an emissions pathway from recent trends and existing policy announcements. It falls well short of achieving zero carbon by 2050. *Societal Transformation* and *Technological Transformation* describe two distinctly different pathways to zero-carbon led by individual behaviour change and community action, and reliance on technological solutions respectively. The final scenario, *Oxfordshire Leading the Way*, sees the county generating high levels of renewable energy locally, while reducing reliance on private transport and enhancing natural ecosystems.

Thirdly, building on Killip and colleagues' 2015 paper, we provide reflections on the process of engaging with local stakeholders, including on how the focus of the low carbon agenda has changed in the last six years. Whereas our report in 2014 reported on the status of, and prospects for, the low carbon sector as a major driver of economic growth, the focus is now on transitioning the entire economy to zero carbon. In the meantime, climate change has risen up the list of priorities for local policymakers and businesses, meaning that our 2021 report is attracting greater scrutiny and interest. We conclude by summarising the shared features of all zero-carbon pathways, outlining the implications of this research for those seeking to achieve net-zero before 2050, and the impacts of COVID-19.

Progress on decarbonising Oxfordshire's economy

Progress on reducing greenhouse gas emissions in Oxfordshire has been roughly in line with other areas of the UK when considering growth in population and GDP (see Figure 2). Total CO_2 emissions in 2018 were 4.1 Mt[1] (1.2 % of the UK total), representing a 27 % reduction since 2008, despite an increase in population of 7.6 % over the same period (BEIS, 2020).

In recent years, Oxfordshire has been undergoing significant growth in housing development, with plans for 100,000 new homes to be built between 2011 and 2031. We estimate that Oxfordshire's population could increase by 32 % over this period, so it is essential that emissions are 'decoupled' from growth. Recent evidence shows that decoupling has begun in Oxfordshire (Figure 2). Between 2011–18, over 26,000 new dwellings were built, the population increased by 5 %, and GDP grew by 34 %. Over this period, demand for gas, electricity and transport remained roughly constant, representing an annual reduction in energy intensity of around 5 %. CO_2 emissions fell by 17 % over this period, which indicates that in 2018, Oxfordshire was on track to achieve the target agreed by the local authorities of achieving a 50 % emissions reduction by 2030.

This is a clear success story, demonstrating that significant progress on climate mitigation can be achieved in a short space of time. Energy efficiency policies have helped to drive down energy usage associated with appliances, buildings and vehicles; and UK electricity generation has become substantially greener in the last decade, as the share of coal-fired generation has been eroded by cleaner-burning gas, and the rapid deployment of offshore wind. In Oxfordshire, solar photovoltaics produce the largest share of renewable generation (72 %), with 453 MW of capacity. This represents 3 % of the UK total solar photovoltaic capacity: double what might be expected if a region's installed renewable energy capacity matched its share of national emissions. Oxfordshire's technical potential for wind generation is lower than many coastal and mountainous UK counties, and much of the potential from landfill gas and waste has already been harnessed. Local electricity currently meets around 15 % of demand, and there is significant potential in the coming years to increase this by expanding solar capacity.

1. Emissions data is only available for CO_2 at a local level, not other greenhouse gases (GHGs). UK emissions of CO_2 make up 81 % of GHGs, with the remainder from methane (11 %), nitrous oxide (5 %) and fluorinated gases (3 %).

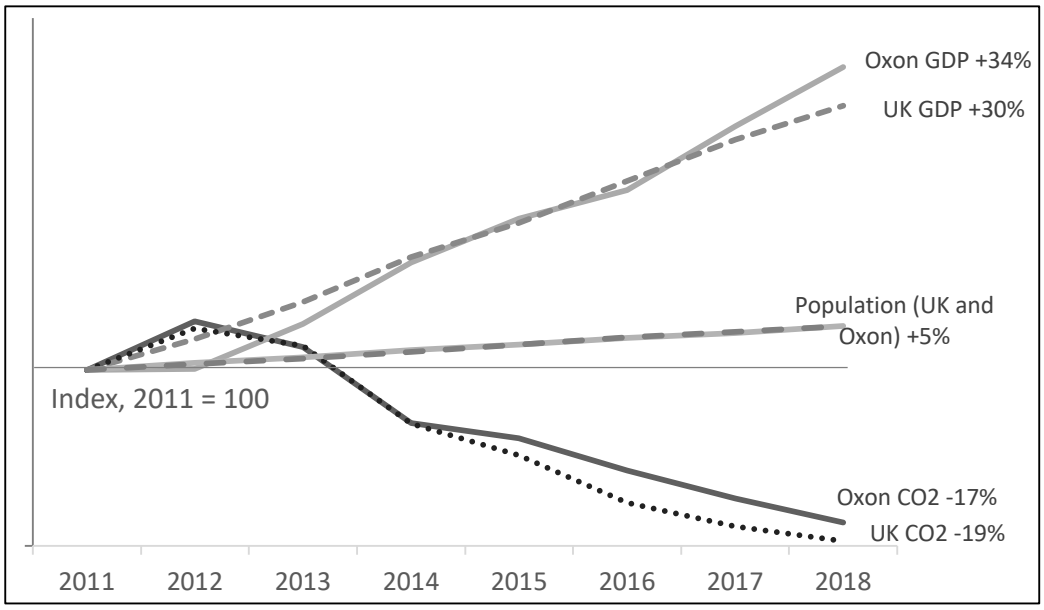

Figure 2. Relative change in GDP, population and, CO_2 emissions for Oxfordshire and the UK, 2011–2018.

Progress on renewable heat, upgrading the energy efficiency of the building stock and decarbonising transport has been far slower, however. A previous national policy to require all new homes to be 'zero carbon by 2016' was abandoned in 2015 (The Guardian, 2015). A new 'future homes strategy' promises zero-carbon standards by 2025, with many details still to be worked out (MHCLG 2021). In the meantime, new homes are built to 2013 standards and the vast majority of new homes are supplied with natural gas for heating, indicating a need to undergo expensive retrofit in coming years. Retrofit of existing homes has also suffered from national policy failures, including the Green Deal, which was halted in 2015 (Rosenow and Eyre, 2016) and, more recently, the Green Homes Grant (The Guardian, 2021).

The transport sector remains heavily reliant on fossil fuels, as the share of zero emission vehicles as a share of the total fleet remains very low. However, the uptake of electric vehicles (EVs) is increasing rapidly. In 2019, 3.3 % of all new cars registered in the UK were ultra-low emissions vehicles (ULEVs[2]), whereas in the first half of 2020, this figure climbed to 8.7 %. There is also a recent shift towards the uptake of 100 % battery electric vehicles (BEVs), when compared to plug-in hybrid electric vehicles (PHEVs). In 2019, new BEV registrations exceeded PHEVs for the first time, and during Q2 of 2020 (a period of national 'lockdown' related to COVID-19), the proportion of new BEVs doubled compared with the previous three months, reaching 7.4 % of all new car registrations. The cause of this shift is yet to be determined, but coincides with an increase in BEV models available, improvements in their performance, and reductions in travel due to COVID-19, some of which is expected to be sustained.

Uptake of ULEV in Oxfordshire exceeds the national average. By the middle of 2020, there were 4,381 ULEVs licenced in Oxfordshire, of which 2,200 were BEVs. This represents less than 1 % of licenced vehicles in the county, but the numbers of zero emission vehicles are growing by nearly 50 % per year. Although uptake of ULEVs is relatively faster in Oxfordshire than the UK as a whole, it is worth noting that adoption lags behind many European states. Whilst ULEVs represented 23 % of all new vehicle registrations in the UK in December 2020, this figure was 72 % in the Netherlands, 49 % in Sweden, and 27 % in Germany (International Council on Clean Transportation, 2021).

The 2014 report on Oxfordshire's Low Carbon Economy (Patrick et al., 2014) set out three scenarios outlining pathways to 2030 with different levels of ambition. Analysis of trends in the intervening years shows that the 2014 scenarios relating to transport (share of EVs in new fleets, number of private and public chargepoints) are likely to be underestimates. The most ambitions scenario assumed that just 25 % of new vehicle registrations would be ULEVs by 2030. While considered a stretching target at the time of writing, this figure now looks conservative, and will be overtaken following the decision, in 2020, by the UK government to bring forward its ban on new fossil fuelled vehicles to 2030; meaning that by law, 100 % of new registered vehicles will be ULEVs by that date.

By contrast, progress with decarbonising heating in buildings has been slower than estimated. Uptake of renewable heat technologies (including heat pumps) has been minimal, with fewer than 0.5 % of Oxfordshire households installing measures under the UK's main subsidy scheme, the Renewable Heat Incentive. Home energy efficiency retrofit has been very sporadic, with UK policies such as the Green Deal and Green Homes Grant failing to create a functioning market. The expansion of renewable electricity supply has been more successful, with 453 MW installed capacity in 2019 (72 % of which is solar). While the rate of expansion has fallen between the medium and high ambition scenarios set out in 2014, this has slowed in recent years due to the decline of public subsidy. It is expected that as the price of solar photovoltaics continues to fall, installations will accelerate however.

2. In the UK a ULEV is currently defined as having tailpipe emissions of under 75 gCO_2/km under test conditions, which includes electric-only vehicles and many plug-in hybrid fossil-electric vehicles. In 2021, this definition is expected to be changed to <50 gCO_2/km.

Table 1. Net-zero targets set by Oxfordshire Local Authorities.

Local Authority	Carbon neutral council operations	Area-wide goal
Oxfordshire County Council	2030	2050
Cherwell District Council	2030	2030
Oxford City Council	2030	2040
South Oxfordshire District Council	2025	2030
Vale of White Horse District Council	75 % reduction by 2025 Aspires to net-zero by 2030	75 % reduction by 2030 Net-zero by 2045
West Oxfordshire District Council	2030	2050

An analysis of land use and carbon sequestration was excluded from our 2014 analysis, but these play an important role in addressing climate goals. Based on detailed analysis of land-use, natural capital mapping, and using the Woodland Carbon Code to calculate sequestration, we estimate around 23 Mt of carbon is stored in Oxfordshire's soils and vegetation, and an additional 100,000 t is sequestered each year. In recent years, housing and other development has led to the loss of arable and managed grassland, but also to the loss of some areas of semi-natural grassland, woodland, scrub, wetland and urban trees and green spaces. In addition, pasture is being converted to arable land in some areas, and vegetation is under stress from climate change. These changes result in loss of the carbon stored in soil and vegetation, as well as loss of the future ability to sequester carbon. From analysis of data from Ordnance Survey Mastermap we estimate that approximately 2,700 ha of land was sealed due to development between 2014 and 2020. Even if this land were all arable (with relatively low soil carbon), around 180,000 t of carbon stored in the topsoil would have been lost.

Scenarios for a zero-carbon Oxfordshire

There is widespread agreement on the need to drive down emissions and achieve a zero-carbon economy in Oxfordshire by 2050, in line with the UK as a whole. In fact, of the six local authorities, four have expressed ambitions to achieve net-zero across their geographical area well before this date (Table 1). Although political ambition and public support is very welcome, the scale of the challenge should not be underestimated. We discuss the feasibility of achieving net-zero in advance of national targets in the next section.

Our scenarios build on comprehensive modelling undertaken by the UK's National Grid (NG) in developing their *Future Energy Scenarios* (FES). These scenarios have been designed to demonstrate distinctly different pathways for achieving a zero carbon economy by 2050, including different kinds of technological innovation, and levels of social, behavioural and cultural transformations. They each rely to some extent on carbon dioxide removal technologies (mostly bioenergy with carbon capture and storage), but do not include offsets from CO_2 removal overseas. While the assumptions and storylines can be challenged on the basis of economic and social viability, the National Grid's scenarios are widely considered to be a robust and credible tool for thinking about the future.

Our four scenarios align with their most recent FES (National Grid, 2020), and include three distinct pathways to achieving zero-carbon (*Societal Transformation*, *Technological Transformation* and *Oxfordshire Leading the Way*[3]). These are contrasted with a business-as-usual scenario (*Steady progression*) (see Table 2).

Where available for Oxfordshire, data on key indicators such as energy demand, renewable generation, and the uptake of electric vehicles are used as a starting point and combined with modelling by NG to extrapolate figures for 2030 and 2050. However, population growth on a national scale is forecast to be far more modest than in Oxfordshire. We therefore adjust the underlying calculations based on expected growth in housing and population, which are consistent across the four scenarios.

The three zero-carbon scenarios are intended to illustrate different possible pathways to eradicating carbon emissions. *Societal Transformation* is characterised by widespread public engagement with the decarbonisation challenge, with individuals, families, communities and businesses taking bold action to upgrade the energy efficiency of their buildings, reduce their reliance on the car, install rooftop solar and zero carbon heating systems, and reduce consumption of animal produce, thus freeing up farmland for restoring carbon-sequestering habitats. While this scenario is intended to highlight the *behavioural potential* for emissions reductions, it also involves the rapid deployment of a vast array of technologies, including electric vehicles, heat pumps, smart appliances and solar photovoltaics, so can be said to illustrate the *socio-technical* nature of the energy transition.

Technological Transformation, on the other hand, has been designed to demonstrate what options are available to achieve zero-carbon emissions with the least change to existing cultural norms, consumer preferences and social practices. Here, new housing developments continue to be built around the assumption of ubiquitous car usage, and albeit electric, the number of private vehicles increases. The energy efficiency of the building stock is improved comparatively slowly, focusing on the most cost-effective measures. Following a national ban on new gas boilers in the 2030s, sections of the natural gas grid are repurposed for Hydrogen use, and domestic heating systems are replaced with an even share of heat pumps and hydrogen-ready boilers. In this scenario, Oxfordshire relies to a greater extent on technological developments, infrastructure investment and policy decisions made outside the county. It is unlikely, for instance, that significant quantities of hydrogen would be gener-

3. *Societal Transformation* and *Technological Transformation* have been adapted from NG's *Consumer Transformation* and *System Transformation* respectively.

ated within the county, so this scenario involves Oxfordshire's expenditure on energy being exported to other regions of the UK and beyond. The result of this technological pathway is that the cost of energy increases for the billpayer, as a high proportion of heat generated by expensive Hydrogen boilers and heat pumps is lost through inefficient building-fabric. Consequentially, fuel poverty remains a major concern, and those who benefit most from the transition are the few with assets such as rooftop solar and electric vehicles, which are used to take part in flexibility markets to reduce bills and generate income. Without dietary change, less land is available for nature restoration and there is a narrow focus on monoculture tree plantations with little biodiversity value.

By contrast, our *Oxfordshire Leading the Way* scenario maximises the co-benefits of decarbonisation, with cost savings and revenue generation distributed amongst a wider portion of the population. Driven by an engaged community and innovative businesses, this pathway involves a high proportion of renewable generation assets being owned by the local community, and a ten-fold increase in solar capacity. By 2050 solar farms occupy around 1 % of total land area, and the loss of agricultural land is more than compensated for in terms of food production by a shift towards low-meat diets. Reduced car-usage is driven by extensive pedestrianisation measures implemented by Oxford City and the market towns, workplace charging levies, the proliferation of low traffic and higher density neighbourhoods, and the expansion of shared transport options. In this scenario, Oxfordshire's strong research and innovation sector continues to develop, and clean-tech businesses become major employers, driving zero-carbon economic growth in the county.

In 2014 Oxfordshire had 272,000 homes, with ambitious plans for a further 100,000 new homes by 2031 (a 37 % increase). Although some have cast doubt over whether all 100,000 new homes planned for 2031 will be built in the face of local opposition, house-building is ongoing and land has now been allocated for the majority of all 100,000. Wanting to avoid taking a political stance, our scenarios take the relatively uncontroversial approach of assuming these are all constructed. No local stakeholder is yet willing to speculate on the need for new housing beyond 2031, given the public scrutiny which will ensue. The National Infrastructure Commission speculated that 1million new homes would be needed along the Oxford-Cambridge arc by 2050, but it is unclear where these will be located, nor whether they would be additional to existing plans for development. For our scenario modelling for net zero, we assumed a rate of housebuilding beyond 2031 of 4,000 dwellings per year, and highlighted the need for these to be zero-carbon developments.

Table 3 provides a detailed breakdown of the key indicators associated with each of the four scenarios. Figures are provided for both 2030 and 2050 to illustrate the changes needed in the medium and longer term.

Reflections and discussion: navigating the local politics of decarbonisation

The 2014 report on Oxfordshire's Low Carbon Economy was influential amongst local stakeholders such as the local authorities and the Local Enterprise Partnership. Its findings were also cited in the Clean Growth Strategy (BEIS, 2017), a key policy document constituting part of the UK Industrial Strategy. Part of its success seems to be due to its focus on the potential for economic growth associated with low carbon innovation. It was estimated that the low carbon sector generates £1.15bn (€1.33bn) in annual revenue, representing 7 % of Oxfordshire's economy, and these figures have been widely used to justify inward investment. Less often cited were the elements of that report highlighting the need for radical action on domestic energy efficiency retrofit, nor the need for changes in travel behaviour.

The context for the 2021 report is very different. Since 2018, public concern for climate change has increased, and governments around the world have been declaring climate emergencies and setting net-zero targets. As the economy decarbonises, it is increasingly difficult to focus on only the economic growth opportunities provided by the low carbon sector, rather what actions need to be taken across all sectors in response to the climate emergency. As such, the 2021 report focuses on the social, political and technical changes needed to eliminate carbon

Table 2. Scenarios for a zero-carbon Oxfordshire.

Scenario name	Summary characteristics
Steady Progression	Extrapolates from existing trends and already-announced policies. Low levels of energy efficiency, renewable heating and continued reliance on private transport. Does not achieve zero carbon by 2050.
Societal Transformation	Individual behaviour change and environmentally-conscious consumer choices. High adoption of active travel, public transport and telecommuting. Strong support for local renewable generation, flexible use of electricity, and doubling of woodland. Does achieve zero carbon by 2050.
Technological Transformation	Decarbonisation is driven by technical solutions with relatively lower impact on individuals and businesses. Hydrogen-ready boilers are installed as 'drop-in replacements' for existing gas boilers, and so fewer heat-pumps are deployed. All small vehicles are electrified, but number increases and congestion worsens. Does achieve zero carbon by 2050.
Oxfordshire Leading the Way	High levels of public support and strong local policies drive early and ambitious action. Solar capacity increases ten-fold from today, reaching 6 % of all UK solar generation and meeting 52 % of local electricity demand. Demand for transport with the proliferation of pedestrianised areas, low traffic neighbourhoods and shared mobility hubs. Does achieve zero carbon by 2050.

Table 3 – List of key scenario indicators, for 2030 and 2050.

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	9,000	280,000	9,000	150,000	9,000	280,000	Supply chains and governance arrangements will take 5–10 years, so few changes occur before 2030. There are currently 295,000 homes in Oxfordshire. Extrapolating from Local Authority forecasts and current trends, we estimate there will be 360,000 homes by 2030 and 440,000 by 2050.
Average EPC rating for all buildings	D	D	D	B	D	B	D	B	
Coverage of business networks dedicated to achieving zero-carbon (% of total number of businesses)	1 %	5 %	5 %	95 %	5 %	50 %	5 %	95 %	Examples include Zero Carbon Oxford Partnership and Oxfordshire Greentech, but more are needed.
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	
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.
TRANSPORT									
Battery electric vehicles as proportion of all light vehicles on the road	25 %	95 %	70 %	99 %	50 %	99 %	70 %	99 %	Currently <1 %. The total private vehicle fleet or car ownership rates are assumed to vary according to scenario (see text).
Domestic and workplace charge points	80,000	200,000	130,000	165,000	105,000	175,000	110,000	150,000	There are roughly 2,000 to 2,500 chargers currently.
Public charge points	7,000	18,000	18,000	25,000	21,000	26,000	30,000	36,000	There are roughly 240 public chargers currently. Includes shared residential charge points (e.g. on street). The European Commission recommends 1 public chargepoint is installed for every 10 EVs on the roads (Transport & Environment, 2018).
% Telecommuting	10 %	15 %	30 %	40 %	10 %	20 %	25 %	35 %	Defined as percentage of labour force working primarily from home
Active travel investment	£10 (€12)	£15 (€17)	£20 (€23)	£40 (€46)	£15 (€17)	£30 (€35)	£25 (€29)	£40 (€46)	Per capita, per year, including capital and revenue based on 2021 prices.

Scenarios	Steady Progression		Societal Transformation		Technological Transformation		Oxfordshire Leading the Way		Notes
Indicator	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	
ELECTRICITY SUPPLY									
Solar generation (GWh)	500	880	850	2,100	700	1,400	1,050	3,900	Solar generation was 382 GWh in 2019. In ST and TT, solar capacity remains 3 % of UK total. In OLTW, this increases to 4 % by 2030 and 6 % by 2050.
Total renewable electricity supply (GWh)	660	1,000	1,000	2,200	870	1,500	1,300	4,000	Renewable generation was 533 GWh in 2019.
Renewable electricity supply as a percentage of electricity demand	16%	16 %	25 %	27 %	23 %	23 %	31 %	52 %	Current generation represents 15 % of demand
FLEXIBILITY									
Percentage of households with time-of-use (TOU) electricity tariffs	6 %	54 %	29 %	73 %	10 %	60 %	35 %	83 %	Flexibility figures are taken directly from National Grid's 2020 scenarios.
Percentage of households utilising vehicle to grid technology	0 %	5 %	3 %	26 %	0.2 %	11 %	5 %	45 %	Percentage of all households, although not all own vehicles, nor have access to off-street parking.
LAND USE									
Hectares of land used for ground-mounted solar generation	390	670	610	1,500	610	1,200	600	2,600	Assuming capacity factor of 12 % and a conservative power density of 1 MW/ha.
Percentage of land used for ground-mounted solar generation	0.15 %	0.26 %	0.23 %	0.57 %	0.24 %	0.45 %	0.23 %	0.99 %	This is calculated based on an area for Oxfordshire of 260,500 ha (2,605 km^2).
Hectares of trees planted per year	15	15	434	434	209	209	434	434	In *Societal Transformation* and *Oxfordshire Leading the Way,* tree cover will double in Oxfordshire, to 18 % of all land. In *Technological Transformation* this is not achieved due to competition for land.
Hectares of agroforestry, hedgerows and garden trees added per year	0	0	2,327	2,327	0	0	2,327	2,327	

emissions across the entire economy, and does not include economic analysis of the scale or potential of zero-carbon activity, in financial terms. While we argue that climate action warrants investment and policy intervention on its own merit, we are aware of the significant influence that can be yielded with financial projections, and deliberated extensively over our decision to exclude these. As well as focusing on producing a report with scientific merit, we share the project steering group's goal of positioning this document to attract attention to, and investment in, Oxfordshire as a leader for climate action. However, the inaccuracies and assumptions associated with modelling the economic impact of a whole-system transformation over three decades, not to mention the uncertainty associated with Brexit and COVID-19, led us away from this analysis.

Another key difference is the fact that climate change has now risen up the political and policy agenda at all levels of governance. At the national level, it is becoming clear that post-Brexit Britain is attempting to position itself on the international stage as a leader on climate action, and recent announcements such as the *Ten Point Plan for a Green Industrial Revolution* (HM Government, 2020) have been made in light of its presidency of the 2021 UN Climate Change Conference. COP26 is also motivating local action, and the UK government recently called for submissions from local areas to showcase their sustainability projects at the conference in November 2021, to which several stakeholders in Oxfordshire responded. Our report will contribute towards this marketing activity.

Local authorities in the UK also appear to be competing to be seen as climate leaders, but in some cases it seems that ambition trumps realism. 300 UK authorities (87 %) have now declared a climate emergency, with many setting medium-term targets for decarbonising their own operations, as well as area-wide goals in advance of central government. Cherwell and South Oxfordshire District Councils, for example, have expressed ambitions for their predominantly rural areas to fully decarbonise by 2030 (see Table 1). While this ambition is laudable, the practical implications of such rapid change render these aims unrealistic. The entrenched use of fossil fuels for heating and transport in particular means that decarbonising these sectors through a combination of efficiency, electrification and the potential use of hydrogen will require substantial investment, individual lifestyle change, concerted action across the public, private and third sectors, all supported by strong policies and system change at the national level. Even with all these elements in place, the transition is likely to take decades. We recommend that Oxfordshire's local authorities work towards a shared date for reaching zero carbon, not before 2040.

That said, for urban areas in countries with 2050 net-zero targets, we speculate that achieving zero-carbon emissions in advance of that date is technically feasible. Oxford City, for instance, has set a target for 2040, by which time it will have to have replaced all gas-fired boilers with low carbon alternatives (primarily building-scale heat-pumps, but with some district heating networks supplied by zero carbon sources). In August 2021, Oxford is implementing a zero-emission zone covering a small number of city-centre streets. Ten years after the UK's ban on the sale of new fossil fuelled vehicles (in 2030), the city would need to have extended this zone to cover the entire city, with consolidation centres located at its periphery where those heavy-goods vehicles still relying on fossil fuels can deposit their goods. While challenging to implement, such a scenario is not unfeasible. Of course, such moves taken by cities rely on the full decarbonisation of national electricity generation using wind turbines, solar photovoltaics, nuclear and biomass plants largely installed in rural and offshore locations.

Clearly then, whilst net-zero targets seem to have become a political badge of honour, this accomplishment cannot be achieved in geographical isolation, and will depend on effective cooperation between governance institutions at multi-levels. After all, counties are not sovereign territories, nor does it make economic, social or technological sense to decarbonise sub-national regions independently of one another. Consensus around the urgent need for climate action is a new political phenomenon, and there are many questions yet to be answered about how the roles and responsibilities for driving down emissions should be allocated – to which institutions, and at what geographical scales. While Oxfordshire has established itself as a leading region for low carbon innovation, research, and investment in solar generation, its ability to decarbonise its economy remains constrained by the limited devolution of infrastructure funding, renewable subsidies and strategic planning powers. With the UK said to have one of the most centralised governance structures in Europe (Agbonlahor, 2015; Institute for Public Policy Research, 2019), the ability of sub-national regions to achieve net-zero depends to a significant extent on national policy.

This is not to suggest that Oxfordshire speaks with a single voice when it comes to strategic planning, however. The sensitivities of local and regional politics made themselves apparent when receiving comments on early drafts from the project steering group. As mentioned above, significant housing development is underway in Oxfordshire, new housing growth and strategic road infrastructure have attracted widespread controversy, including fervent opposition from residents in towns and villages in rural districts which are set to expand substantially. Despite the controversies around planning and land use, our chapter on land-use and sequestration received notably less attention from the variety of stakeholders making up our steering group. Although it is not clear why, it appears that the knowledge and skills required to comment on natural ecosystems, agriculture and biodiversity are more specialised when compared with energy, transport, eco-innovation and buildings. This assertion warrants further investigation, not least because the emissions (and sequestration) associated with land-use are significant, and choices made by planning authorities in the near term have major ramifications for renewable energy generation, food production, mobility patterns and biodiversity. Whereas the 2014 study excluded land-use from its analysis, it is for these reasons that we chose to integrate this into a report on net-zero.

In their article and presentation at eceee's Summer Study 2015, Killip and colleagues reflected on the experience of working with a range of local stakeholders to analyse the scale and potential of the low carbon economy in Oxfordshire. They described encountering epistemic differences, manifest in how many words and phrases meant different things to different stakeholders. These included 'low carbon' itself, as well as 'innovation', 'investment', 'infrastructure', 'clusters', 'networks' and 'living laboratories'. When producing the 2021 report, such interpretative differences have re-emerged, despite climate

change and sustainable business becoming more mainstream. The steering group could not agree on a definition of 'living laboratories' for instance, despite the existence of a wide body of peer-reviewed literature having defined this concept in precise terms (Voytenko et al., 2015; Bulkeley et al., 2018). Some local stakeholders considered these to be larger in scale than individual projects, and one contributor considered the whole county of Oxfordshire to be a living lab. Perhaps more significantly and concerningly, it seems that while the phrase 'net-zero' has become a badge of honour, there remains some disconnection between the positivity and optimism surrounding this target, and the serious challenges associated with decarbonising heat, power and transport, which will require unprecedented investment and wholesale societal change.

Conclusions

This paper has provided a summary of the report titled 'Pathways to a Zero Carbon Oxfordshire', which found that the county is currently on track to achieving its 50 % emissions reduction target, on the basis of substantial achievements in decarbonising electricity supply and increased energy efficiency. However, progress remains slow when it comes to decarbonising transport, reducing reliance on fossil fuels for heating, and enhancing the natural environment for increased carbon sequestration.

This study outlined different scenarios for eliminating carbon emissions from the local economy by 2050. Our *Steady Progression* scenario falls well short of stated climate aims, and illustrates the scale of change needed to move from business-as-usual to zero-carbon economic activity. The three pathways which achieve net-zero by 2050 adopt distinct approaches. *Societal Transformation* is led from the bottom up, with householders adopting new technologies and practices, and community groups corralling action. *Technological Transformation*, by contrast, relies on systemic changes driven at the national level, including the deployment of hydrogen for heating and other technical solutions which require the least change to individual behaviour. Finally, *Oxfordshire Leading the Way* mirrors the widespread cultural and behavioural changes seen in *Societal Transformation,* and combines this with high deployment of new local electricity generation using solar photovoltaics.

Despite their distinct differences, the three net-zero pathways have several features in common, with similar implications. Each of them involve:

- the substantial expansion of solar generating capacity in Oxfordshire. Large ground-mounted solar parks are preferred in *Technological Transformation*, with others seeing the widespread deployment of rooftop arrays. The business case for new installations will rely on the falling price of photovoltaic panels, battery storage, and will face the challenge of geographically varied grid constraints.
- a major programme of retrofit for existing homes and non-domestic buildings, led by strong and consistent national policy including significant subsidy.
- a strict approach to planning for new homes and developments so that they do not result in increased carbon emissions from the building, transport, or energy sectors, and so that land take is minimised to protect carbon stored in soils and vegetation.
- substantial increases in electricity demand, driven by heat and transport, requiring grid reinforcement and flexibility provided by various means.
- the phase out of gas boilers and fossil-fuelled modes of transport.
- a need for innovation in food production to maintain or increase output while agricultural land makes way for development, and Oxfordshire grows its fair share of biofuels.
- restoration of ecosystems and natural capital, for enhanced sequestration and increased biodiversity, enabled by reduced consumption of animal produce to free up farmland (otherwise emissions are simply displaced).

Our analysis shows that despite several local authorities having stated ambitions to achieve zero emissions well in advance of 2050, this is unlikely to be achieved, especially in rural districts. There is a need for consistency amongst local stakeholders, and we suggest that there are other ways to demonstrate leadership on climate change besides target setting, such as in using planning powers to insist on zero-carbon development. The fact that climate ambition has become politically attractive is welcome, and we are anticipating significant local attention once the report is launched in May 2021. This attention also means that we have had to tread carefully to avoid political controversy, for instance when modelling housing and infrastructure growth.

More than 1,000 people in Oxfordshire have lost their lives to COVID-19, and the pandemic has had a severely detrimental impact on nearly all residents and businesses in Oxfordshire. In the short term, energy demand and carbon emissions have fallen sharply. As the economy gets back on its feet, it is imperative that the sustainable practices adopted by businesses and individuals, such as telecommuting and active travel, are supported and sustained. As businesses struggle to stay afloat following the COVID-19 pandemic, there is a risk that investment in zero carbon measures are deprioritised. And yet, businesses are more aware than ever of the need to build resilience, and ensuring that their products, services and operations are compatible with a zero-carbon future is now a crucial component of effective risk management. Unlike the period following the economic downturn in 2008, recent evidence suggests that public support for climate action is likely to remain high (CAST, 2020), so that although strong policy interventions such as low traffic neighbourhoods and pedestrianisation will continue to divide opinion, local policy-makers can continue to push the zero carbon agenda with confidence.

It is encouraging to see climate action becoming a priority for sub-national regions, and it is clear that with international renown for research and innovation, local authorities and economic development organisations in Oxfordshire consider the sustainability transition to be an opportunity for inward investment and wealth creation. Nonetheless, there are elements of the transition which will be costly and unpopular amongst some groups. The challenges associated with decarbonising Oxfordshire's economy include retrofitting the vast majority of the building stock, installing expensive renewable heating sys-

tems and restricting the use of fossil-fuelled vehicles in towns and cities – none of which will be easy. Just as we have revisited Killip and colleague's 2015 eceee paper six years later, we hope in future to look back on this study and update on progress.

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