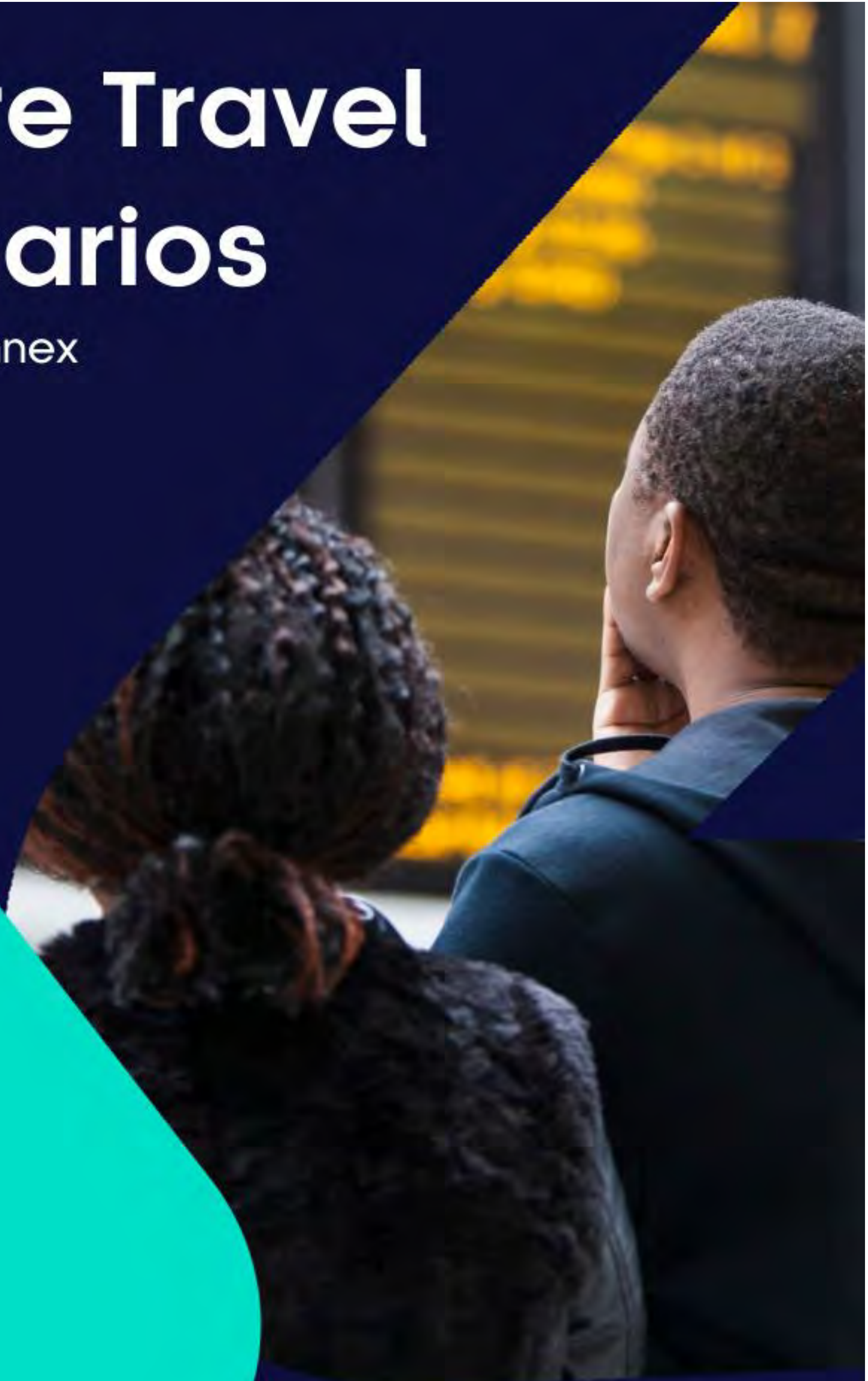
Future Travel Scenarios

Technical Annex



December 2020

TRANSPORT FOR THE NORTH

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1 Introduction

This is a Technical Annex to TfN's 2020 Future Travel Scenarios report, setting out in more detail the work undertaken to represent the Future Travel Scenarios within the Analytical Framework, an integrated system of modelling tools covering all pan-Northern travel and modes of transport. The annex is structured as follows:

2. Analytical Framework overview
3. The Northern Economy and Land-Use Model (NELUM)
4. The Northern Carbon tool (NoCarb)
5. Representing the Future Travel Scenarios in NELUM and NoCarb
6. Detailed results of modelled Future Travel Scenarios
7. Interaction visualisation dashboard
8. Next steps.

2 Analytical Framework overview

Application of the Future Travel Scenarios is not a one-off exercise but is being integrated into TfN's wider planning and decision-making processes, outlined in Figure 1.

The Future Scenarios form one of five decision-support frameworks used by TfN to develop the strategy, policies, programmes and projects to achieve our vision and objectives. Figure 1 below shows how they sit alongside the Analytical Framework, the Appraisal Framework and the Monitoring and Evaluation Framework, all of which are guided by TfN's Assurance Framework, which represents a step-by-step process for making decisions on transport interventions.

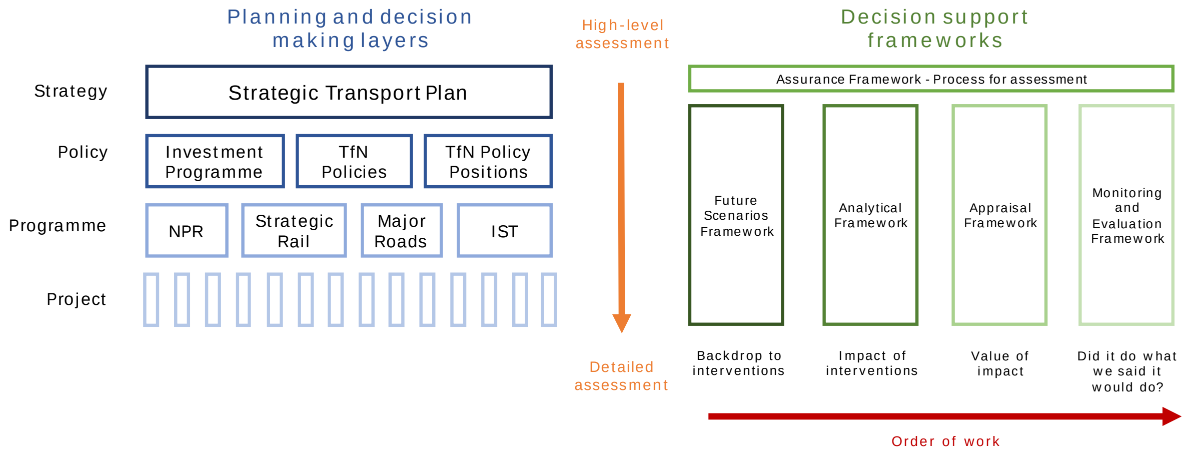

Figure 1: TfN's Decision-Making processes

From top left to bottom right, Figure 1 can be explained as follows:

- Strategy is the top layer of planning, in which objectives are set and high-level decision-support helps to identify a series of broad interventions required to achieve these objectives. From strategy, we begin to develop more specific interventions as we move from policies through programmes and down to projects, each of which requires a more detailed level of decision-making support.
- The Assurance Framework is an overarching step-by-step guide to making decisions on which interventions to proceed with. It sets out the appropriate level of detail for assessment of interventions within each layer of planning and decision-making, and how each of the other four frameworks should be used.
- As described above, the Future Scenarios Framework provides a series of possible backdrops to the intervention under consideration, as well as further evidence via a continuous feedback loop to support further strategy development.
- The models within the Analytical Framework are then used to estimate the impacts of the intervention under each scenario, including how travelers, households and businesses in the North respond.

- The Appraisal Framework values these impacts in each scenario across a range of objectives, either in quantified monetary terms, or using a more qualitative assessment. At this point, a decision will be made on the preferred way forward for the intervention, based on a rounded assessment of how it performs within the Appraisal Framework across each scenario.
- Once a decision has been made and the intervention implemented, the Monitoring and Evaluation Framework will examine the actual outcomes and help assess how fit-for-purpose the other decision support frameworks are for informing subsequent intervention decisions.

The Analytical Framework aims to provide a consistent approach to data, modelling and appraisal across the different travel modes and regions of the North. This document describes how the Future Travel Scenarios have been represented within the Northern Economy and Land-Use Model, part of the forecasting system of the Analytical Framework. A schematic overview of the forecasting system is shown in Figure 2, which highlights three main elements:

1. NELUM: The Northern Economy and Land-Use Model (NELUM) is primarily designed to test a wide range of future scenarios and estimate the wider impacts of transport investment on the economy, including the responses of households, businesses and property developers. NELUM contains a detailed segmentation of people and businesses and a more aggregate representation of the transport system. NELUM is described in more detail in section 2.
2. NorTMS: The Northern Transport Modelling System (NorTMS) is primarily designed to test the conventional transport impacts of investment, containing a less detailed segmentation of people and businesses, and a much more detailed representation of the transport system. NorTMS is comprised of the Northern Rail Modelling System (NoRMS) and the Northern Highway Assignment Model (NoHAM).
3. NorMITs: The Northern Model Integration Tools (NorMITs) is a flexible library of Python scripts designed to provide functionality including:
    - a consistent set of segmented land-use data and travel demand for base and future years of both NorTMS and NELUM; and
    - a means to translate information on network and service capacity restraint from NorTMS into NELUM to allow as robust as possible an estimation of changes in generalised cost whilst maintaining reasonable runtimes. This is referred to as NELUM's 'Aggregate Network Model', one of the NorMITs cost tools.

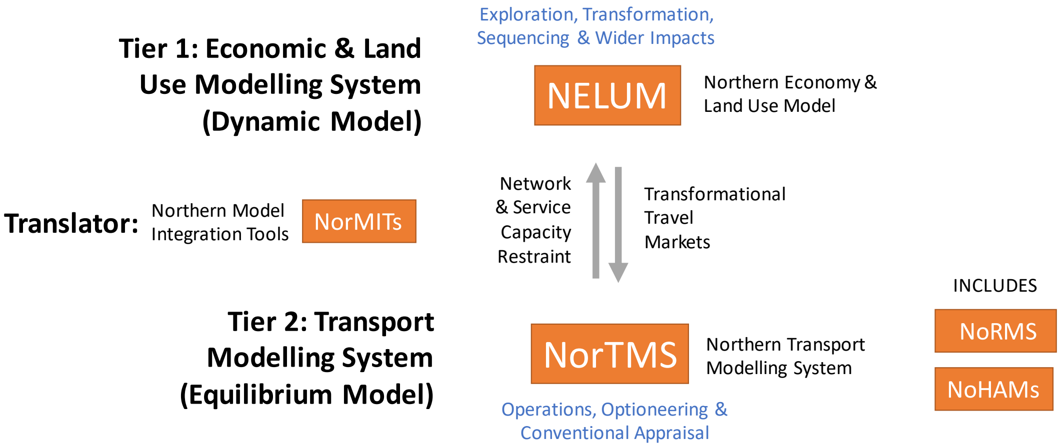

Figure 2: High-**level schematic of the forecasting system within TfN's Analytical Framework**

The other component of the Analytical Framework covered in this report is the Northern Carbon tool (NoCarb), which processes travel demand data from either NELUM or NorTMS, combined with scenarios for the vehicle fleet over time, to produce estimates of carbon emissions from the North's transport network. This is covered in more detail in section 3.

A note on proportionate modelling. We recognise that the value of scenario analysis is the ability to make multiple parallel assessments of a how a policy or programme will perform in different futures to help decide relatively quickly whether it is the right course of action. The first stage of this analysis should therefore use a qualitative assessment or a relatively fast-running, simple model that allows a high-level assessment. In some cases, as simple spreadsheet model may be appropriate for this task, but in TfN's case, we have access to NELUM, which runs in about 20 minutes due to its relatively aggregate representation of the transport network. NELUM is therefore ideally suited for this kind of early-stage scenario analysis, although it does also have important uses as an economic appraisal tool, discussed below. Beyond early-stage scenario analysis, at the stage of business case development, it is necessary to test the performance of policies and programmes in different scenarios using TfN's more detailed transport models. This was not the immediate priority for TfN for reasons outlined above, but it is an important next step. Work is currently underway to implement these quantified scenario representations in the more detailed NorTMS model. This work is described in section 8, Next Steps.

3 The Northern Economy and Land-Use Model (NELUM)

The Northern Economy and Land-Use Model (NELUM) is a Land-Use Transport Interaction (LUTI) model developed by Steer for Transport for the North (TfN). NELUM's primary purpose is to test how investment in transport, sometimes coupled with changes to land-use policy, will affect the economy of the North of England and the UK as a whole.

NELUM can be used in two main ways:

- Providing a strategic and economic appraisal of the wider impacts of transformational transport investment for business cases, aligned to Government guidance; and
- Assisting the development of long-term strategies under future uncertainty, using wide-ranging scenario analysis, including interaction with non-transport policies.

This section provides an overview of NELUM, sufficient to understand how the model is used to represent the Future Travel Scenarios. If the reader would like to understand more about how NELUM works, TfN is intending to publish a more detailed report on the model in the coming months.

NELUM is a System Dynamics model, an approach that uses the basic building blocks of stocks and flows. Figure 3 shows a very simple stock and flow structure. It expresses the idea that, in a given zone, there is a 'stock' of households, and as time progresses this stock changes as new households arrive, and others depart via the inflow and outflow. The arrivals and departures are expressed in households per year and are the result of households making decisions about whether to live in the zone. The 'stock', represented by the rectangle, is the number of households present at any time; technically it is calculated as the integral of the inflow minus the outflow; intuitively it is the accumulation of the arrivals minus the departures.

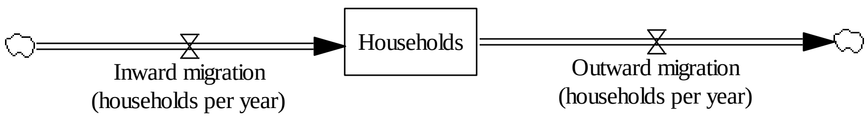

Figure 3: The migration of households

The modelling software handles the integration calculations automatically. Inflows, outflows and stocks are re-calculated repeatedly at small time intervals. NELUM recalculates these values 16 times per year, a small enough interval for the simulation to be effectively continuous in simulated time. The same structure is replicated for every zone and every household type in the model.

A high-level structure diagram for NELUM is shown in Figure 4, illustrating flows of data into, out of and within the model.

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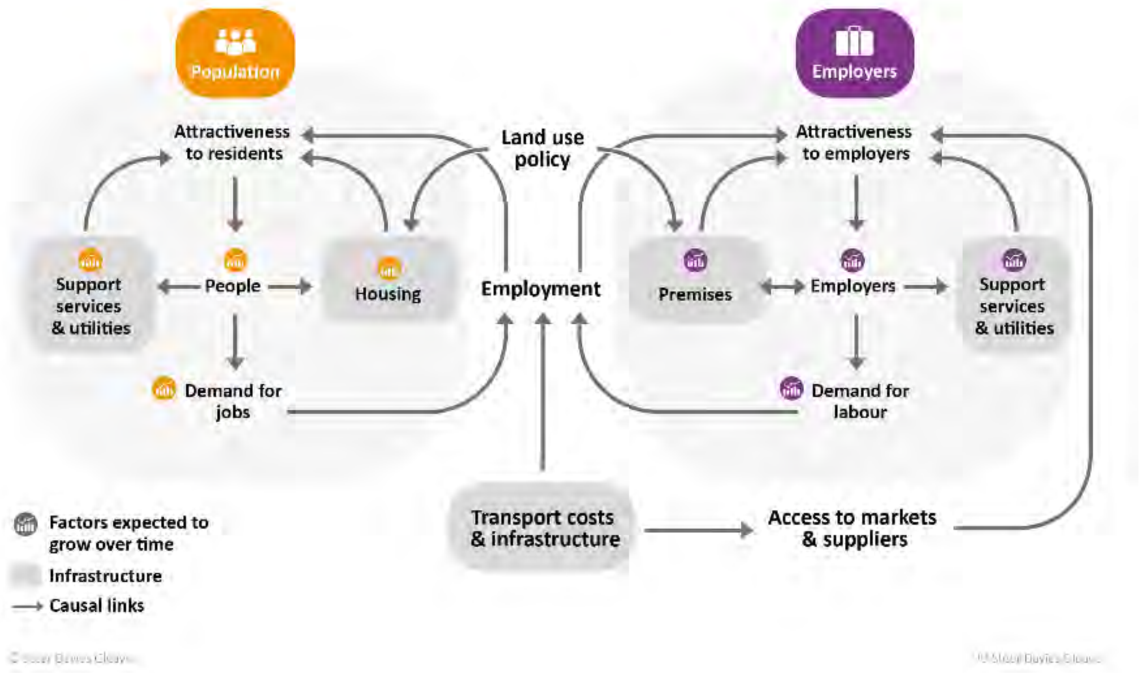

Figure 4: NELUM structure

NELUM has 211 zones, shown in Figure 5, made up of MSOAs[1] or aggregations of MSOAs within the North and larger zones outside the North (LADs[2] or aggregations of LADs, except in core city centres). Some inputs for the Future Travel Scenarios are also defined at the level of 'sectors'. These sectors are groupings of zones aligned to Mayoral Combined Authorities and Local Enterprise Partnerships, so inputs defined at that level are intended to represent local changes in transport policy.

[1] Middle-level Super Output Area
[2] Local Authority Districts

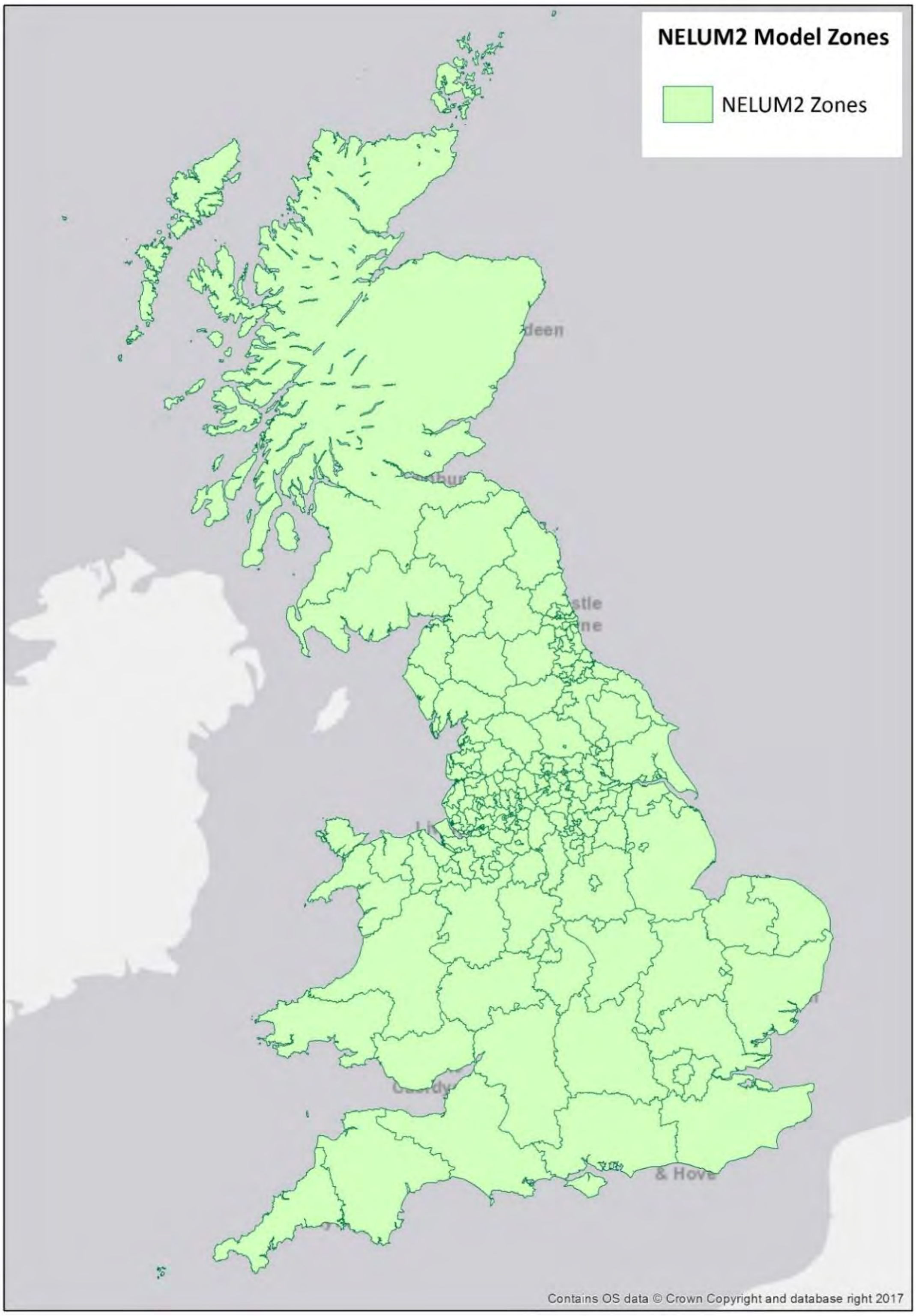

Figure 5: NELUM zoning system

Model dimensions: NELUM has many economic and demographic dimensions, summarised in Table 1.

Attribute	Number	Classes
Zone	211	• 177 dynamic internal zones • 34 external zones
Employers	8	• Advanced Manufacturing • Knowledge Service Sectors • Primary • Finance and Business • Education • Retail and Catering • Other Industry & Manufacturing • Other Services
Commercial property	4	• Commercial Offices • Shops Hotels & Restaurants • Research & Manufacturing Premises • Other
Housing	5	• Detached • Semi-Detached • Terrace • Flats & Other • Communal establishments
Households	5	• NS-SeC 1 & 2 • NS-SeC 3, 4 & 5 • NS-SeC 6 & 7 • NS-SeC 8 • NS-SeC L15 (Students)
Skills (based on Census occupation categories)	5	• Non-Work Age • Manual • Skilled • Expert • Students
Transport modes	4	• Highway (private) • Bus • Rail • Active Modes
Time periods	2	• Peak • Off peak

Table 1: NELUM dimensions

Outputs from the model include:

- Numbers of jobs, and associated Gross Value Added (GVA);
- Population, workforce and unemployment rates;
- Travel volumes and mode shares.

Business dynamics: The rate at which businesses migrate into or out of a zone will vary as it becomes more or less attractive to locate in. In NELUM, a zone can become more attractive to businesses if:

- suitable premises are available;
- they can recruit a suitable workforce; and
- they have access to customers and suppliers in the right sectors.

Three separate zonal 'attractiveness multipliers' are estimated for each of these zonal characteristics:

- For premises, NELUM calculates a weighted effective vacancy rate by business type (sector) using a table of preferences for type of commercial unit (e.g. Finance and Business require office units).
- For workforce recruitment, staff must be recruited from the pool of accessible job seekers, that is, people actively looking for work and who live within acceptable travel times and have the right skills. If employers find they cannot recruit enough staff they will be left with unacceptable vacancy rates, and net new start-ups will slow or stop.
- For access to customers and suppliers, attractiveness depends on both transport accessibility and the proximity of businesses in different sectors. The model recognises that some businesses prefer to cluster with similar businesses, whilst others prioritise access to the retail sector or public services such as education and health, or the general population. For each business in each zone, a value is calculated based on accessibility to the key sectors for that business.

A compound zonal attractiveness is calculated using the product of these three multipliers. In addition, a lag time of two years is applied recognising that businesses do not typically respond instantaneously to changes in attractiveness of different locations.

Household dynamics: The rate at which households migrate into or out of a zone will vary as it more or less attractive to live in. In NELUM, a zone can become more attractive to households if:

- attractive housing is available; and
- attractive, accessible employment is available.

Two separate zonal 'attractiveness multipliers' are estimated for each of these zonal characteristics:

- For housing availability, NELUM calculates a weighted effective vacancy rate by household type using a table of household preferences for type of housing unit (e.g. higher income households prefer larger houses on low density sites).

- For employment accessibility, each new household has a socio-economic classification (based on NS-SeC levels) which has a corresponding structure in terms of the number of economically active, working age adults with different skill levels (e.g. lower NS-SeC households will typically have lower skill levels). Potential workers are available for employers to recruit into 'posts' based on their skill level and willingness to travel (i.e. transport improvements can improve access to jobs).

Again, the model calculates the compound zonal attractiveness using the product of these two multipliers. As with businesses lag time of two years is applied.

Transport model: NELUM is equipped with its own internal discrete-choice based, multi-modal transport model. Having an integrated transport model is an advantage over other LUTI models, as it allows the transport response to be estimated at every time step. This means NELUM is a 'full' LUTI, in which we not only estimate the impact of transport changes on land-use, but also the subsequent impacts of land-use changes on the transport network. The fact that the transport and land-use models run concurrently also means that the practical issues of passing data from one model to another and back again are avoided.

The model's transport cost inputs consist of matrices of travel times and fares between each pair of zones in the model. Each transport mode has its own matrix of transport costs. Where a separate mode is used to get to and from the main mode used for a journey, the matrix also includes travel time not spent on the main, such as the cost to travel to/from rail stations. The costs are calculated to and from the population-weighted centroid of each zone.

For the major rail and road corridors, an internal strategic network model can vary travel times with the volume of trips using the corridor. These networks are simplified versions of TfN's more detailed road and rail model networks (see Figures 6 and 7), with a correspondence between the two sets of networks to allow collation of data for each 'strategic link' from the detailed links.

Figure 6: NELUM strategic rail network and its source detailed network

Figure 7: NELUM strategic highway network and its source detailed network

For road, this represents delays caused by congestion, and for rail the discomfort of crowding as a perceived journey time increase. Rail travel times and capacities are taken from TfN's Northern Rail Modelling System (NoRMS), which makes it possible to test any rail intervention in NELUM that has already been tested in NoRMS. Highway travel times and capacities are currently being calibrated to Highways England Trans-Pennine South (TPS) Regional Transport Model (RTM) to establish a similar relationship to that developed with NoRMS. Vehicle operating costs for cars are calculated by the model based on a matrix of distances between zones and a cost per kilometre.

Bus and active modes are also represented in NELUM. The bus cost matrix includes both bus fares and travel times base on real timetable information estimated using the TRACC software[3]. The active mode cost matrix represents a mixture of walk and cycle modes calculated using distances and assumed speeds, with the split between modes being represented using a weighted average speed. A higher cycle mode share leads to a higher weighted-average speed for active modes.

Calibration: The 2015 base year calibration was undertaken in two stages.

Stage 1, known as 'Dynamics off', uses a version of the model in which population and employer numbers are held fixed (i.e. the dynamic relationships are not active), in order to build a travel-to-work (TTW) trip matrix. Calibration at this stage is to ensure that:

- Highway trip volumes match Highways England's Regional Traffic Models;
- Rail trip volumes match TfN's NoRMS model; and

Bus and active mode trip volumes match Census TTW matrices and NTEM volumes for non-TTW trips.

In parallel to the production of this report, TfN is developing a new 2018-based version of NELUM that will be calibrated to an improved, semi-observed 2018 travel matrix for all modes and trip purposes being developed by TfN. It is worth noting that some of the underlying mechanisms and relationships in the model may be altered in nature and scale by the effects of the pandemic and subsequent recovery, and we will continue to review evidence on this and update the functionality of NELUM as more becomes available.

Stage 2, known as the 'Stabilise run', takes the synthesised TTW trip matrix and allows all the internal dynamics to run to a position of near-equilibrium. Calibration at this stage is to ensure that the model does not contain any instabilities in terms of employers and households when its dynamic functionality is turned on. The end-point of the stabilise run then becomes the starting point for all subsequent runs of the model.

A note on calibration adjustments. Close to finalisation of this report, an issue was identified whereby the introduction of new road and rail inputs from TfN transport models had caused the bus mode share in NELUM to be too high. As there was insufficient time to recalibrate the model, an off-model adjustment was made to bus trips to reach a level closer to the observed mode share in the base year. This issue will be resolved as part of the current new 2018-based version of NELUM described above.

Approach to growth and constraints: Scenarios of population and employment are fed in to NELUM in the form of the available land required to accommodate that population and the businesses to provide that employment. This means that those forecasts are treated as a 'target' level of growth that cannot be exceeded,

[3] https://www.basemap.co.uk/tracc/

rather than inputs that are always met. For the Future Travel Scenarios, this means zonal population and employment inputs provided to the model should be thought of as targets, and in general the output population and employment results are slightly below these targets.

Once these target inputs are established, NELUM can then be used to model the impact of transport constraints on the region's ability to achieve its growth potential. First, an unconstrained run is carried out, in which transport costs are not subject to increases caused by changes in demand (congestion and crowding). Following that, the transport network constraints are applied, increasing costs as demand rises, making it more challenging to find appropriate matches between housing, households, jobs and businesses. This approach frames transport constraints as causing 'lost growth' that can be 'bought back' by investing in improved transport infrastructure, with the constraint is a representation of the market failures and frictions preventing workers being matched to appropriate jobs at an optimum rate.

4 The Northern Carbon tool (NoCarb)

The NoCarb Tool has two primary functions:

- Project the make-up of future fleets using sales scenarios.
- Calculate emissions using fleet, emissions and demand inputs.

These two functions are displayed in the NoCarb Tool's process flow in Figure 8, represented by the fleet projection and greenhouse gas (GHG) tools in the middle grey box.

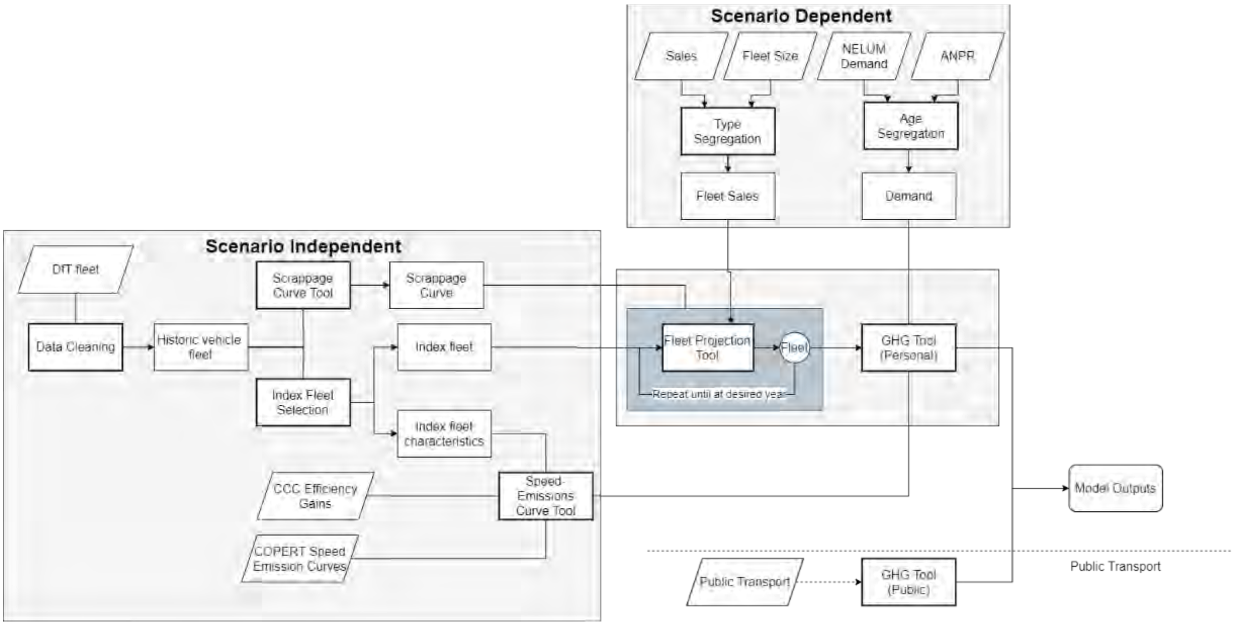

Figure 8: A visual representation of how the NoCarb Tool works.

1. Fleet projections

The tool begins by reading in and cleaning 2018 fleet data drawn from a detailed extract of DfT's Vehicle Licensing Statistics. This includes addressing missing values and applying transformations to support compatibility with other data sources[4]. This creates the historical fleet from which the baseline fleet is derived (in this case, 2018 was selected as the baseline year) and provides the basis for calculating scrappage curves[5].

[4] For example, the zoning levels are mapped from local authorities to TfN's modelling zones to support merging with demand data estimated from TfN's NELUM model.

[5] A scrappage curve describes the proportion of a vehicle type that survive year on year. This provides the basis for calculating how many vehicles registered in a particular year are likely to remain in the fleet in future years.

These two outputs are fed into the fleet projection tool, which:

- Applies the scrappage curve to a given fleet to remove older vehicles from the subsequent year's fleet.
- Uses future sales and fleet growth estimates (developed for each Future Travel Scenario) to calculate the number of vehicles that will be injected into the subsequent year's fleet, broken down by vehicle type, segment and fuel.

Starting with the baseline fleet, this process is repeated to derive future fleets from 2019 to 2050.

2. Calculate private road vehicle emissions

The second function of the NoCarb tool is to calculate road emissions for a given year. As a first step, this involves taking baseline fleet characteristics associated with average CO_2 emissions, engine size and mass (derived from manufacturer estimates) and taking weighted averages of these values by segment, fuel and vehicle age. Using these values alongside some of the NAEI factors (EEA, 2018), a formula is then used to derive real-world correction factors (which adjust for real-world driving conditions, such as driving while using air conditioning) for each vehicle group[6]. These corrections are in turn applied to speed emissions curves sourced from the NAEI to produce updated, baseline speed emissions curves.

Currently, TfN's NELUM model is used to estimate vehicle kilometres travelled at different speed bands in each zone and on each road type (motorway, urban and rural). This data is then paired with Automatic Number Plate Recognition data from DfT and fleet data for a given year (baseline or projected) to assign demand by vehicle type, segment, vehicle age and fuel. The process is repeated for each scenario year for cars, though only once for vans and HGVs (for the baseline year). Instead, growth factors associated with each Future Travel Scenario are applied to van and HGV demand in future years. Following this, scenario-dependent reduction factors are applied to HGV demand to account for improved logistics efficiency and freight modal shift to rail.

Emissions estimates for each Future Travel Scenario are derived by applying the baseline speed emissions curves to the relevant, disaggregated demand data for each year. For future years, carbon emissions reductions associated with new cars to reflect ongoing efficiency improvements are also applied in each year[7]. Further emissions changes are modelled through the entry of zero and ultra-low emission vehicles into the fleet via sales scenarios, and additional vehicle kilometre reductions to represent further demand-side policies.

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[6] As 'real world uplift' parameters were only available for cars, real-world correction factors were not applied to speed emissions for vans and HGVs.

[7] These reduction factors were sourced from the Committee on Climate Change Fifth Carbon Budget scenario, based on assumptions about EU regulation for new vehicle standards.

3. Calculate public transport vehicle emissions

Public transport estimates were derived and treated separately in the tool. Aggregate bus emissions in the North in 2018 were derived from DfT's *Road Traffic forecasts* (Scenario 1)[8], while equivalent rail estimates were calculated by taking the product of fuel consumption per mile (by vehicle type) and distances travelled[9]. Reduction factors were then applied to baseline public transport estimates in line with each Future Travel Scenario the details of which are outlined below.

[8] As DfT's estimates did not explicitly relate to 2018 (instead covering the years 2015, 2020 and beyond), emissions estimates for 2018 were derived through interpolation.

[9] Emissions per mile data was sourced from TfN's Rail Operating Expenditure (OPEX) model, which uses factors supplied be Network Rail, and timetable data (which provided information about distances travelled) was sourced from a 2015 version of TfN's Northern Rail Modelling System, which uses data from MOIRA.

5 Representing the Future Travel Scenarios in NELUM and NoCarb

The main inputs to model the Future Scenarios can be categorised as:

- Socio-economic inputs: economic and demographic projections of GVA growth, population and jobs at each zone represented in the model (based on the Northern Powerhouse Independent Economic Review)
- Transport inputs: Including road, rail and other transport innovations and demand pricing options, e.g. rail fares (based on literature review and testing)

Only drivers of change that are not within TfN's direct policy remit have been included within these inputs, i.e. drivers that can be considered to be external or exogenous. Drivers that are excluded are changes to the infrastructure of the North's strategic road and rail networks, as these are the main focus of TfN's Investment Programme. These interventions will be separately tested using the Future Travel Scenarios, so it is important that there is no duplication of their effects in any of the scenario inputs.

Where possible, evidence on plausible assumptions for different inputs has been drawn from the literature or primary analysis of relevant, available data by TfN. In these cases, we have referenced the sources of information used. However, in many cases the inputs are representing policy choices, typically at a national level, which will depend on the preferences of future politicians and the nuanced circumstances in which they find themselves. In these cases, collective professional judgement has been used to set the inputs at plausible levels for each scenario. As described in the main Future Travel Scenarios report, these collective judgements have not only involved a group of TfN officers, but also TfN Partners and the Expert Panel assembled to inform the development of scenarios. In cases where such judgement has been used, the sections below make this clear.

5.1 Socio-economic inputs

Population, employment and productivity projections

Forecasts of population, employment and productivity growth were taken from TfN's Northern Powerhouse Independent Economic Review (NPIER).

The NPIER provides a detailed understanding of the prosperity and productivity gap that exists between the North of England and the rest of the UK, and a high-level assessment of how that gap could be narrowed. A key output of the NPIER is a 'transformational' future scenario in which the North experiences higher levels of population, employment and productivity growth relative to 'business as usual', as part of the UK Government's Levelling-Up agenda.

Within the modelling of Transport for the North's Future Scenarios both, Business as Usual and Transformational NPIER scenarios were used. Data for 2018 to 2050 was extracted from NPIER scenario outputs at LAD level and then converted to NELUM zones.

As described above, population and employment growth are represented in the model through increases in the land available for housing and businesses in each zone, providing the model with additional capacity to build more housing and commercial property, with associated population and jobs. This approach ensures that the population and employment inputs, alongside the transport network, are self-consistent and sufficiently matched to each other to allow jobs to be filled and people to be employed.

It should be noted that new land added within the model does not necessarily translate to growth in the model. Other factors, such as attractiveness of the place in terms of transport connections and proximity to employment need to be in place to support the growth, as described in section 2 of this annex. As a consequence of the zone attractiveness, the NELUM population and employment results are slightly lower than the land inputs.

Productivity growth is used as a further input into the NELUM model and varies between Transformational and Business as Usual scenarios. The values were taken from NPIER and used to calculate the compound growth at NELUM zone level.

Note on the update to NPIER 2020

To reflect recent changes in the economic landscape, including the impact of the COVID-19 pandemic, TfN commissioned a further revision to the NPIER scenarios in 2020, reflecting reflect the latest thinking from the Office for Budget Responsibility (OBR) and the Office for National Statistics (ONS). The underlying methodology has not, however, been changed.

In the short term the 2020 forecasts are intended to capture the economic disruption caused by COVID-19 in 2020, and current OBR assumptions on the recovery in 2021 and 2022. The OBR now forecasts UK gross value added (GVA) to decline by almost 13% in 2020 and employment by 5%. Jobs are expected to continue to fall in 2021 while GVA will recover strongly in the year as a result of a rapid rebound in productivity. According to the OBR, GVA is expected to recover to its 2019 size in 2023 and jobs will return to 2019 levels in 2024 under both scenarios in the UK.

Changes since the previous 2019 update:

- The Office for Budget Responsibility has lowered its economic forecasts, both for the immediate period and over the long term. Both population growth and productivity growth were revised using weaker assumptions.
- This changed the resulting forecasts for the Northern economy from 1.7% in the 2019 scenario to 1.2% a year in GVA terms to 2050 in the updated scenario under the Business as Usual Scenario.
- Weaker UK outlook means slower Business as Usual growth for the North.
- The Transformational scenario looks harder to achieve than it did a year ago.

	Business as Usual scenario		Transformational scenario	
	North	UK	North	UK
Annual growth, 2015–50, % y/y				
GVA[10]	1.2	1.4	1.7	1.5
Jobs[11]	0.1	0.2	0.4	0.3
Productivity[12]	1.1	1.2	1.3	1.2
Population	0.2	0.3	0.4	0.3

Table 2. NPIER Updated figures for annual growth in GVA, jobs, productivity and population.

It is important to note that the 2020 versions of the NPIER scenarios have not been through the same governance processes as the 2019 update and are primarily intended for use in TfN programmes.

Spatial distribution of growth

Annual growth for each zone in the North was calculated by translating the employment and population projections provided within NPIER into additional land for each zone in NELUM. In order to represent the different spatial growth distributions in each scenario, total growth between 2030 and 2050 was spread across zones using a zonal weighting factor that varied as a function of initial population, area type and scenario. Zones were categorised into urban, sub-urban and rural area types, using a modified version of the DfT's National Trip-End Model area type classification[13]. This variation in our scenarios allowed to compare changes in the mix of different types of settlements to help us understand the transport implications.

For example, in the Prioritised Places scenario, zones with rural area type had the highest weighting and zones with urban area type the lowest. The aim in this case was to achieve growth for rural zones over the whole period to 2050. This methodology was applied for years post-2030 in each scenario, given the time that would be needed for a major shift in regional land-use policy and trends.

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[10] GVA ("gross value added") represents the value of the output of goods and services, less the value of inputs in their production (such as materials and labour costs). It is a measure of the contribution to GDP made by an area, industry, or sector of the economy. GVA is measured in real terms (in this case, at constant 2016 prices).

[11] "Jobs" relates to the number of jobs in an area, while "employment" (or "workplace employment") is the number of workers taking up jobs in an area, regardless of where they live. This measure differs from jobs as some workers can have more than one job.

[12] Productivity is defined as the average GVA per job in an area.

[13] The main adjustment being the introduction of an area type that more adequately represents city centres in the North. More information will be published by TfN on this approach in early 2021.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Distribution	As per NPIER BAU			NPIER BAU	Growth more evenly shared, with shift towards rural areas from 2025 onwards		NPIER TRA	Growth highest in sub-urban areas, but also some growth in urban and rural areas.		NPIER TRA	Growth mainly weighted towards urban areas with very little growth in rural areas.	

Table 3. Distribution of growth in population and employment across the Future Travel Scenarios.

5.2 Transport inputs

The following section includes detailed scenario assumptions and adjustments made in NELUM and NoCarb.

For the levers to have an effect in a desired year (2030, 2040 and 2050), all the NELUM modelling inputs were introduced 5 years prior, to allow time for the change to take place.

Increased working from home

Increased home-working has been represented in the model through a varying commuting trip rate. Recent analysis of the Annual Population Survey by the ONS show that those with higher-skilled occupations are more likely to work from home than the lower-skilled workers. Table 5 presents the estimated percentage of workers from each SOC category[14] that have ever worked from home. Within the NELUM model the households are divided into three SOC categories: higher skilled, medium skilled and skilled. The classification is based on grouping of SOC categories and is presented in Table 6.

Highly Skilled	Skilled	Low Skilled
89%	29%	9%

Table 5: Percentage of workers in each occupation category who have ever worked from home.

[14] SOC stands for Standard Occupational Classification – a common classification of occupational information for the UK.

SOC classification	NELUM classification
1 Managers Directors And Senior Officials	Highly Skilled
2 Professional Occupations	Highly Skilled
3 Associate Professional And Technical Occupations	Skilled
4 Administrative And Secretarial Occupations	Skilled
5 Skilled Trades Occupations	Skilled
6 Caring Leisure And Other Service Occupations	Low Skilled
7 Sales And Customer Service Occupations	Low Skilled
8 Process Plant And Machine Operatives	Low Skilled
9 Elementary Occupations	Low Skilled

Table 6: Occupation category groupings.

Each scenario assumes a different number of days working from home (Table 7) but considers the extent to which working from home is possible in each of the occupation groups. Percentages shown in Table 5 were multiplied together with the percentage of weekdays where commute trips do not take place to adjust the commute trip rates for each skill/occupation grouping.

Scenario	1. Just About Managing			2. Prioritised Places			3. Digitally Distributed			4. Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
No. of days WFH	1	1	2	1	1	1	2	2	3	1	1	2

Table 7: Days worked-from-home (WFH) by scenario and year in occupations where this is possible - input settings for NELUM.

Electric Vehicle sales

Electric Vehicle (EV) sales inputs are represented in the Future Travel Scenarios as inputs to the NoCarb fleet model, as described above. The level of EV sales will depend on a combination of technological progress and the level of Government policy support at the national and local levels. Initially, EV sales scenarios were based on published Government planning assumptions (DfT, 2020) and assumptions from the CCC's 2019 Net Zero scenarios (CCC, 2019a). However, shortly before publication, the Government published its ten point plan for a green industrial revolution[15], which included a new policy to ban the sale of new petrol and diesel cars and vans by 2030 and the sale of new plug-in hybrids by 2035. TfN scenario assumptions have been updated to reflect this new policy, with the main variation between scenarios now being the rate of increase in EV sales before 2030 and the status of hybrids after 2030.

Scenarios for the electrification of small HGVs are also drawn from CCC Net Zero scenario analysis (CCC, 2019b).

The input assumptions used are summarised in Tables 8 and 9 below, with the car and van fleet outputs from NoCarb shown in Figure 9. HGV fleet outputs are shown in Figure 10.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040
Electric car and van sales	20% BEV, 20% PHEV	60% BEV, 40% PHEV	100% BEV	20% BEV, 30% PHEV	80% BEV, 20% PHEV	100% BEV	30% BEV, 30% PHEV	100% BEV	100% BEV	50% BEV, 30% PHEV	100% BEV	100% BEV

Table 8. Electric Vehicle sales – Cars and vans (BEV = Battery Electric Vehicle, PHEV = Plug-in Hybrid Electric Vehicle) - input settings for NoCarb.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Electric small HGV sales (BEV)	15%	60%	80%	15%	60%	80%	20%	100%	100%	20%	100%	100%

Table 9. Electric Vehicle sales - Electric Vehicle sales – Small HGVs - input settings for NoCarb.

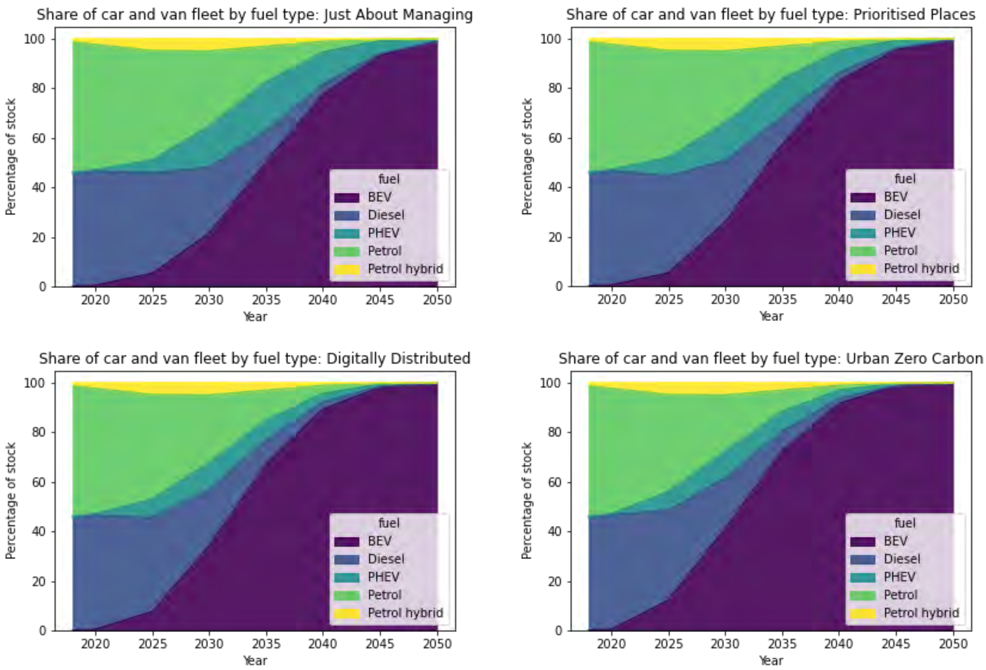

Figure 9. Car and van fleet mix by fuel type and Future Travel Scenario from NoCarb.

15 https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

Hydrogen vehicle uptake

Hydrogen fuel cell vehicles are assumed to only be used in significant numbers in the large HGV fleet, where there are uncertainties about the availability of batteries with sufficient power density to be used for long-distance haulage. As this is an area with a high degree of uncertainty in which a number of possible technologies are competing, we will regularly monitor evidence and update our scenarios accordingly. Evidence on the plausibility of these assumptions has been drawn from the CCC's 2019 Net Zero assumptions. There are only two input scenarios used, one in which hydrogen HGVs are not available (the two lowest decarbonisation scenarios), and another in which they are available based on the CCC's assumptions (the two lowest decarbonisation scenarios). The binary nature of this assumption reflects the significant systemic uncertainty over the scope for production of green hydrogen sufficient to supply the HGV fleet in addition to other uses, such as industrial processes. The input assumptions used are summarised in Table 10 below, with the HGV fleet outputs are shown in Figure 10.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Hydrogen large HGV sales	0%	0%	0%	0%	0%	0%	0%	70%	90%	0%	70%	90%

Table 10. Hydrogen vehicle uptake - input settings for NoCarb.

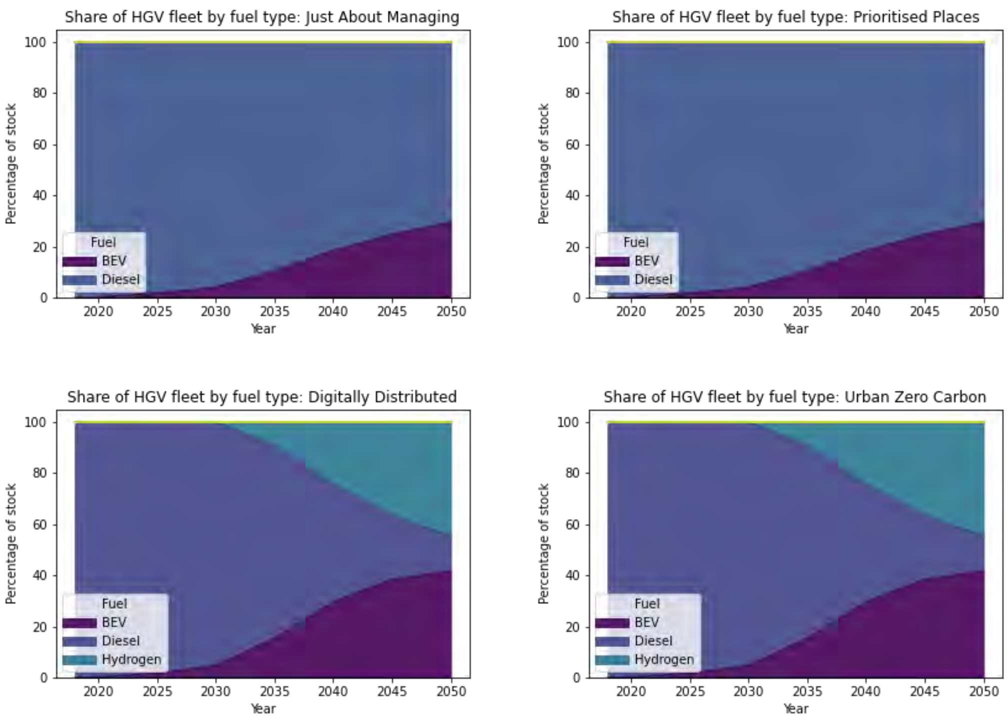

Figure 10. HGV fleet mix by fuel type and Future Travel Scenario from NoCarb

Rail electrification

Rail electrification is modelled in a relatively simplistic way to illustrate the impact on carbon emissions, applying a percentage reduction relative to the 2018 base year rail network emissions. The Government's stated ambition is to decarbonise the rail network by 2040 (Network Rail, 2020), through a combination of electrification and alternative traction rolling stock (e.g. battery and hydrogen trains). In the scenarios which see higher levels of decarbonisation, we have assumed this goal is met whereas in the other scenarios we have assumed only a 50% reduction in rail network emissions by 2050 due to the high costs of electrifying some parts of the rail network. These assumptions are summarised in Table 11.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Reduction in rail emissions relative to 2018	-25%	-50%	-50%	-25%	-50%	-50%	-50%	-100 %	-100 %	-50%	-100 %	-100%

Table 11. Rail electrification - input settings for NoCarb.

Sustainable access to rail station

This input describes the capacity and frequency of public transport and quality of active travel infrastructure as an access mode to rail. This was modelled by reducing costs for access/egress. As described above, these are largely local policies outside of TfN's direct sphere of influence, so are included as external uncertainties. As these uncertainties are related to future policy choices, professional judgement was used to assign plausible values to these reductions. The values were tested based on plausibility for each scenario (Table 12).

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Sustainable access to rail station	No change			10% lower perceived costs for access/egress			No change			20% lower perceived costs for access/egress		

Table 12. Sustainable access to rail station - input settings for NELUM.

Sustainable Transport access

This input relates to the increase in capacity and frequency of public transport and the quality of active travel infrastructure. These changes were modelled by applying a percentage reduction in GJT to public transport as well as active mode. This area of policy is largely led by Local Authorities, subject to the level of national funding available, and is therefore outside of TfN's direct sphere of influence, so is included as an external uncertainty. As this represents an uncertain future policy choice, professional judgement was used to assign plausible values to these reductions. These reductions varied by flow type (within or between sectors) and scenario. A summary of these changes is provided in Table 13.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2060
Sustainable transport access	No change			15% lower bus GJT for intra-sector trips 10% lower GJT for walk/cycle trips			No change			10% lower bus GJT for intra-sector trips 10% lower GJT for walk/cycle trips		

Table 13. Sustainable Transport access - input settings for NELUM.

Micro-mobility

Micro-mobility refers to small, fully or partially motorised forms of transport, such as electric scooters and electric bikes. Cycling and other micro-mobility numbers are strongly dependent on having an infrastructure that is mostly separate from other vehicles. This consideration has been taken into account when setting up input assumptions.

Micro-mobility is not modelled explicitly in NELUM at this stage, but for the purposes of the Future Travel Scenarios, we have chosen to represent it as an adjustment to the active travel mode. Active modes within NELUM are modelled by using an average speed together with zone to zone distances to work out whether a journey between each zone pair can be carried out within a 60-minute limit. To represent innovation and uptake of micro-mobility within TfN scenarios, we added a faster micro-mobility speed to this mix depending on scenario (representing different mode shares of micro-mobility compared to the traditional active travel modes). This increases the speed average and therefore the distance that can be travelled using active mode within the 60-minute limit.

The maximum permitted speed was subject to a debate in the recent DfT's Call for Evidence in 2020, so the speed limits already in place in other countries were used to influence our modelling inputs. Speed limits for e-scooters introduced in Germany are 12.5mph and in France of 15.5mph (Parliament. House of Commons, 2020). The decision was therefore made to use the 12.5mph in the modelling as it is assumed the main areas that could benefit from e-scooters and e-bikes would be cities, where there are likely to be obstacles limiting the speed of either e-bikes or e-scooters.

A speed of 10kph was used for scenarios with lower assumed uptake in micro-mobility, representing a lower share of the active travel mode e.g. Just About Managing. The speed used for each scenario is specified in Table 14.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2060
Micro-mobility	No change	Include micro-mobility in walk/cycle travel time with average speed of 10kph		Include micro-mobility in walk/cycle travel time with average speed of 10kph		Increase speed to 20kph	No change	Include micro-mobility in walk/cycle travel time with average speed of 10kph		Include micro-mobility in walk/cycle travel time with average speed of 20kph		

Table 14. Micro-mobility - input settings for NELUM.

Shared transport/ usership and mobility as a service

Mobility as a Service (MaaS) is a term used to describe digital transport service platforms that enable users to access, pay for, and get real-time information on, a range of public and private transport options (Parliament. Transport Select Committee, 2017).

Capturing full impacts of MaaS within TfN's Future Scenarios is not an achievable or desirable objective due to the intentionally high-level and strategic nature of our modelling. Achieving this would require a new, complex, dynamic and integrated model of all the transport modes, including public and private modes, its demand and supply, as well as their interactions through integrated network.

As a simplified approach, shared transport and MaaS were modelled using an existing bus matrix within the NELUM, improving the travel times and accessibility in this matrix to represent enhanced, on-demand buses.

Shared transport/mobility can be thought of as extension to an already established division between 'local' and 'other' bus services. Local being available to public and set on a regular route, whilst 'other' including longer-distance scheduled services which are also available to the public but are more personalised or part of a MaaS journey (TRL, 2004).

To allow shared transport/mobility to operate within all flow types within the model, the average bus speed was calculated from the bus journey times and zone to zone distances matrices. The speed was used to calculate the travel time between the zones and applied accordingly for each scenario (Table 15).

To adjust shared transport fares between flow types, a similar approach was applied making use of the full bus fare matrix used within NELUM.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Shared transport / MAAS	No change	Bus connectivity for all intra-sector pairs		Bus connectivity for all intra-sector pairs		Bus connectivity for all flow types	Bus connectivity for all intra-sector pairs	Bus connectivity for all flow types		Bus connectivity for all flow types		

Table 15. Shared transport / MAAS settings in NELUM.

Rail GJT reduction over time

Rail Generalised Journey Time (GJT) reductions are generally driven by service quality improvements, which TfN has direct influence over through its policies and programmes of infrastructure investment. Rail GJT reductions from such changes have not therefore been included within the Future Travel Scenarios, which are intended to represent only factors external to TfN's direct sphere of influence. However, there are background technological changes outside of TfN's direct sphere of influence that can influence rail GJT, which have been considered.

Availability and advancement in quality of mobile technology have made rail travel easier especially as the time spent travelling can be spent working. A recent study of this impact has been researched and quantified in the *Rail Demand Forecasting Estimation* report prepared for DfT (DfT, 2016). Introduction of 1% reduction in GJT per annum was tested against other factors that cause demand growth and was applied within NELUM across all scenarios to represent the improvements in mobile communications. This has also been checked against historical rail trends using DfT's NTS reports. The net impact of this assumption is set out in Table 16.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2060
Rail GJT reduction over time	10%	16%	16%	10%	16%	16%	10%	16%	16%	10%	16%	16%

Table 16. Rail GJT reduction over time - input settings for NELUM.

Public transport fare subsidisation

Public transport fare subsidisation includes rail, tram and bus fare subsidisation. As public transport subsidies represent a policy choice, professional collective judgement on plausible levels of change was used, as described at the start of this section. This was also varied by scenario and dependant on flow type level (within and between sectors).

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
PT fare subsidisation	No change			10% lower fares for intra-sector trips	20% lower fares for intra-sector trips 10% lower fares for other trips		No change			20% lower fares for intra-sector trips 10% lower fares for other trips		

Table 17. Public transport fare subsidisation- input settings for NELUM.

Connected and Autonomous Vehicles

This input covers different assumptions for the availability and costs of Connected and Autonomous Vehicles (CAV). Costs and accessibility vary between scenarios for sharing-based services as well as private use by households and businesses.

Assumptions on fleet penetration were drawn from DfT's *Road Traffic Forecasts* 2018 report, which used research from Catapult's *Market Forecasts for Connected and Autonomous vehicles* report. These are shown in Table 16 below.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
CAV fleet penetration	0%	0%	25%	0%	0%	25%	25%	50%	75%	0%	25%	50%

Table 18. Connected and Autonomous vehicles fleet penetration within scenarios.

Previous studies of modelling the impacts of CAVs considered different levels of automation within fleet itself - from driver assistance to fully automated vehicles and those have varying impacts on convenience on different flow types. Only with a significant penetration of the fleet with almost fully autonomous vehicles, the benefits of reducing the distance between vehicles can be achieved and bring in a potential increase to the capacity of the roads. (Atkins, 2016)

Capacity growth rates from Road Traffic Forecasts (DfT, 2018 (Table 12)) were used to calculate capacity benefits on TfN's simplified road type (Motorway, Urban, Rural). Values differ based on fleet penetration scenarios and are applied to individual NELUM highway links based on classification.

In addition, we represented the convenience factor demonstrated by research to date by applying a set reduction in car GJT depending on fleet penetration which is shown in Table 19.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
CAV fleet penetration	0%	0%	25%	0%	0%	25%	25%	50%	75%	0%	25%	50%
Capacity increase on Motorway	0%		10%	0%		10%	10%	20%	31%	0%	10%	20%
Capacity increase on Urban roads	0%		6%	0%		6%	6%	11%	17%	0%	6%	11%
Capacity increase on Rural roads	0%		6%	0%		6%	6%	13%	19%	0%	6%	13%
Convenience factor (represented by car GJT reduction)	3%	4%	5%	3%	4%	5%	5%	5%	7%	4%	5%	5%

Table 19. CAV – capacity benefits and convenience factor applied based on fleet penetration - input settings for NELUM.

Demand Reduction policies and measures

This lever input is concerned with pricing the marginal external costs of car travel and assumes national systems of charging for road use on top of existing operating costs, the scale and scope of which vary between the different scenarios. The increased costs for relevant trips or for all zone pairs were applied depending on scenario (Table 20). As this represents a future policy, the additional increased cost values were based on the professional judgement.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Demand reduction policies and measures to improve use of roads	No change	No change	No change	No change	No change	5% RUC cost increases applied intra sector	No change	5% RUC cost increases applied intra sector	10% RUC cost increases applied intra sector	10% RUC cost increases applied to all zone pairs	15% RUC cost increases applied to all zone pairs	20% RUC cost increases applied to all zone pairs

Table 20. Demand reduction policies to improve use of roads - input settings for NELUM.

Logistics improvements, consolidation centres and freight modal shift

NELUM does not model freight explicitly, but van and HGV traffic are represented on the model's highway network, through an initial base matrix taken from TfN's freight modelling tools and a demand growth rate to account for different levels of goods vehicle demand on the road network, which can affect the levels of congestion. In addition, the freight vehicle kilometres can be further adjusted using assumptions about the effect of policies to improve the efficiency of logistics networks and freight modal shift to rail.

The annual van and HGV vehicle kilometre growth rates for each scenario were drawn from the DfT's *National Road Traffic forecasts* (DfT, 2018). Just About Managing and Prioritised Places used the DfT's reference scenario, whereas Digitally Distributed used and the highest growth scenario (high GDP, low fuel costs) and Urban Zero Carbon used an intermediate growth scenario (high population growth), reflecting moderating environmental policies in that scenario. The assumptions are set out in Table 21. This relatively simplistic approach will be refreshed with a project to model the impacts of the scenarios on freight traffic in more detail in TfN's freight modelling tools, described in section 7.

The impacts policies to improve the efficiency of logistics networks and freight modal shift to rail were drawn from CCC analysis (CCC, 2019a), originally based on research by the Centre for Sustainable Road Freight. These inputs are set out in Table 22.

Scenario	Description		Just About Managing	Prioritised Places	Digitally Distributed	Urban Zero Carbon
Background growth in goods vehicle demand	Average annual growth rate in vehicle kilometres	Van	1.2%	1.2%	1.7%	1.3%
		HGV	0.4%	0.4%	0.3%	0.4%

Table 21. PCU factor for vans and HGVs - input settings for NELUM.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Logistics improvements, consolidation centres and freight modal shift	0%	0%	0%	-5%	-5%	-5%	0%	0%	0%	-5%	-10%	-10%

Table 22. Kilometres reduction relative to initial forecast for vans and HGVs - input settings for NoCarb.

Adjustments to Value of Time

Value of Time (VOT) is used in NELUM in the trip length/distribution and mode split calculations to convert monetary units into GJT in time units. A base year VOT is provided to the model, along with an annual growth rate that the model uses to calculate the current year's value of time. Changes in VOT can also impact mode split because monetary costs for modes that have them (e.g. fuel, fares) typically grow at a different rate to VOT.

Annual change in VOT are based on estimates of income growth and apply to both annual change in personal VoT and in business to business VOT. These growth rates can vary by scenario, because the productivity and associated income assumptions vary by scenario.

For scenarios based on NPIER 'Business as Usual', the growth rate was calculated based on the VOT change between 2018 and 2060 in DfT's current guidance (TAG, 2020). For scenarios based on NPIER 'Transformational' scenario, the VOT growth from the 'Business as Usual' scenario was adjusted using the uplift productivity assumed in the 'Transformational' scenario. These assumptions are shown in Table 23.

Scenario	Just About Managing			Prioritised Places			Digitally Distributed			Urban Zero Carbon		
Year	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Adjustments to VoT growth rate	1.8%			1.8%			2.1%			2.1%		

Table 23. Adjustments to VoT growth rate - input settings for NELUM.

5.3 Limitations, future work and non-modelled drivers of change

The need for regular updates: Throughout the COVID-19 pandemic, there have been significant changes in both travel demand and distribution of travel across modes. The heightened uncertainty in our world highlights the need for a dynamic and flexible approach to modelling. TfN's new approach to Future Travel Scenarios is designed to allow iterative development, so as more up to date evidence becomes available, TfN will seek to integrate it into the Future Travel Scenarios framework on a regular basis. Light-touch updates are planned annually, but we acknowledge that new uncertainties will emerge, and we will never have the ability to confidently forecast the medium- or long-term future of travel. The aim of the TfN's future scenarios is not to forecast but to support robust, evidence-based decision making.

Limitations on current representation of home-working: We have been working closely with partners across the North to monitor travel demand and modal changes throughout the pandemic and partner data broadly aligns with those UK-wide at the current stage. Evidence during the first UK-wide restrictions to tackle the pandemic also indicate a greater prevalence of home working. However, it is also recognised that the North's sectoral composition is one that may not lend itself well to remote working when compared to the rest of the UK. In order to represent this variation, we have taken into account the percentage of workers from each SOC category that have ever worked from home to adjust commute trip rates by reducing them relative to the increase in home working. On reflection, and as we are currently observing, the remote working does not simply translate to a relative reduction in travel. The recent study using NTS data based on 2009 to 2016 shows that those who identified themselves as having worked from home at least once a week, made on average only one less trip per week than regular commuters (Budnitz et al., 2020). This is a useful insight that TfN will continue to research and discuss closely with stakeholders as the time progresses. The assumed number of days working from home for each scenario can also be changed if deemed out of date during the next iteration of TfN's Future Scenarios.

Mobility as a Service (MaaS): MaaS is not explicitly modelled in NELUM but has been represented in a high-level way through adjustments to a more traditional bus matrix. Capturing the full impacts and different scenarios for MaaS uptake would require more development within NELUM and TfN's wider Analytical Framework. Over the next year the Analytical Framework development will include the ability to vary car ownership and car occupancy to better represent, for example, car-sharing and car-clubs. A more significant development effort is needed to represent the complex potential dynamics of interaction between private and public modes in a future MaaS system within the Analytical Framework.

Active modes are another area where more development is needed in the future to improve its representation in NELUM and the Analytical Framework. The main limitations are the aggregation of different sub-modes (walk, cycle, micro-mobility) and the level of spatial aggregation. The current NELUM zoning consists of relatively large areas and so the impact of active mode and micro-mobility is limited to the smaller zones' intra-sector trips. To enable active mode and micro-mobility between sectors, we will to seek to improve our current model zones and consider splitting them further into smaller zones. We will also consider an Analytical Framework tool that splits out the different active modes into cycling, walking and micro-mobility.

Not modelled drivers: Some of the drivers of change identified in the development of the Future Travel Scenarios are beyond the scope of TfN's current Analytical Framework, so have been treated qualitatively. In future, it may be desirable to attempt to model the impacts of some of these drivers on travel demand. For example, the driver 'open markets and sustainable access to international gateways and economic clusters' aimed to represent the increased (or decreased) international movement of people and goods to and from the North driven by an improved access. This was tested through a series of iterations starting with a slight decrease for Prioritised Places and increase for Digitally Distributed scenarios in business land within international airport zones. This approach was however deemed too crude, and difficult to separate from the driver of change representing the spatial distribution of economic growth. As part of our future work programme, there are plans to use a bespoke airport surface access demand matrix, which will improve our ability to represent such effects in the Analytical Framework.

5.4 Quantitative evidence references summary

Table 25 below summarises the sources used to inform the quantitative values used for each driver of change, as described in detail above, including a reference to where professional judgement has been used.

Drivers of change	Source
Policy or exogenous change	Oxford Economics for Transport for the North (2020). "Northern Powerhouse Independent Review" [online]. Available from: (internal) https://www.transportforthenorth.com/wp-content/uploads/Northern-Powerhouse-Independent-Economic-Review-Executive-Summary.pdf
City and town densification	Based on area type classifications and population weights.
Economic growth	Oxford Economics for Transport for the North (2020). "Northern Powerhouse Independent Review" [online]. Available from: (internal) https://www.transportforthenorth.com/wp-content/uploads/Northern-Powerhouse-Independent-Economic-Review-Executive-Summary.pdf
Increased home working	Office for National Statistics (2020). "Coronavirus and homeworking in the UK labour market: 2019" [online]. Available from: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/coronavirusandhomeworkingintheuklabourmarket/2019
Electric car and van sales	Climate Change Committee (2019a). "Net Zero – The UK's contribution to stopping global warming" [online]. Available from: https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/
Hydrogen large HGV sales	Climate Change Committee (2019a). "Net Zero – The UK's contribution to stopping global warming" [online]. Available from: https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/ Climate Change Committee (2019b). Detailed data from CCC Net Zero scenarios shared with TfN [private communication].
Rail electrification	Network Rail (2020). "Traction Decarbonisation Network Strategy" [online]. Available from: https://www.networkrail.co.uk/wp-content/uploads/2020/09/Traction-Decarbonisation-Network-Strategy-Interim-Programme-Business-Case.pdf
Sustainable access to rail stations	Model testing and collective professional judgement on plausibility of inputs and modelled outcomes.
Sustainable transport access	Model testing and collective professional judgement on plausibility of inputs and modelled outcomes.
Micro-mobility	Model testing & collective professional judgement on plausibility of inputs and modelled outcomes. Speed based on: Parliament. House of Commons (August 2020). "Regulating electric scooters (e-scooters)" (HC, 8958) [online]. Available from: https://researchbriefings.files.parliament.uk/documents/CBP-8958/CBP-8958.pdf
Shared transport / MAAS	Based on NELUM bus matrix Research: Transport Systems Catapult (2016). "Mobility as a Service. Exploring the opportunity for mobility as a service in the UK" [online]. Available from: https://ts.catapult.org.uk/wp-

	content/uploads/2016/07/Mobility-as-a-Service_Exploring-the-Opportunity-for-MaaS-in-the-UK-Web.pdf
Rail GJT reduction over time	Department for Transport (2016). "Rail demand forecasting estimation" [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/610059/phase2-rail-demand-forecasting-estimation-study.pdf
Public transport fare subsidisation	Based on NELUM rail and bus GJT matrix and fare matrix.
Connected and Autonomous Vehicles	Department for Transport (2018). "Road Traffic Forecasts 2018" [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/873929/road-traffic-forecasts-2018-document.pdf Atkins for Department for Transport (2016). "Research on the Impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow" [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf Transport Systems Catapult (2017). "Market Forecasts for CAV Report".[online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642813/15780_TSC_Market_Forecast_for_CAV_Report_FINAL.pdf
Demand reduction policies and measures to improve use of roads	Model testing and collective professional judgement on plausibility of inputs and modelled outcomes Initial analysis based on: Department for Transport (2004). "A Feasibility Study of Road Pricing in the UK. Annex B – Modelling Results and Analysis" [online] Available from: https://webarchive.nationalarchives.gov.uk/20090511101532/http://www.dft.gov.uk/pgr/roads/introtoroads/roadcongestion/feasibilitystudy/studyreport/
Logistics improvements, consolidation centres and freight modal shift	Department for Transport (2018). "Road Traffic Forecasts 2018" [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/873929/road-traffic-forecasts-2018-document.pdf Together with NoHAM annualization factors
Adjustments to VoT growth rate	Department for Transport (2020). "TAG data book" [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/898797/tag-data-book.xlsm Oxford Economics for Transport for the North (2020). "Northern Powerhouse Independent Review" [online]. Available from: (internal) https://www.transportforthenorth.com/wp-content/uploads/Northern-Powerhouse-Independent-Economic-Review-Executive-Summary.pdf

Table 25. Summary of quantitative evidence references.

6 Detailed results of modelled Future Travel Scenarios

This section provides an overview of the socio-economic and travel implications of TfN's Future Travel Scenarios. Figures are provided as a change between 2018 (base year) and 2050 ('horizon year').

6.1 Population and employment

Figure 11 shows the next 30 years of population growth in the North across the four scenarios. The differences observed are due to the two different NPIER population scenarios used as inputs to our travel scenarios. The Digitally Distributed and Urban Zero Carbon scenarios reach about 17 million people in 2050 and are based on the 'Transformational' NPIER, which assumes a fixed amount of additional growth above the 'Business as Usual' scenario. Just About Managing and Prioritised Places use this NPIER scenario, which reaches a population about 1 million lower than the 'Transformational' inputs in 2050.

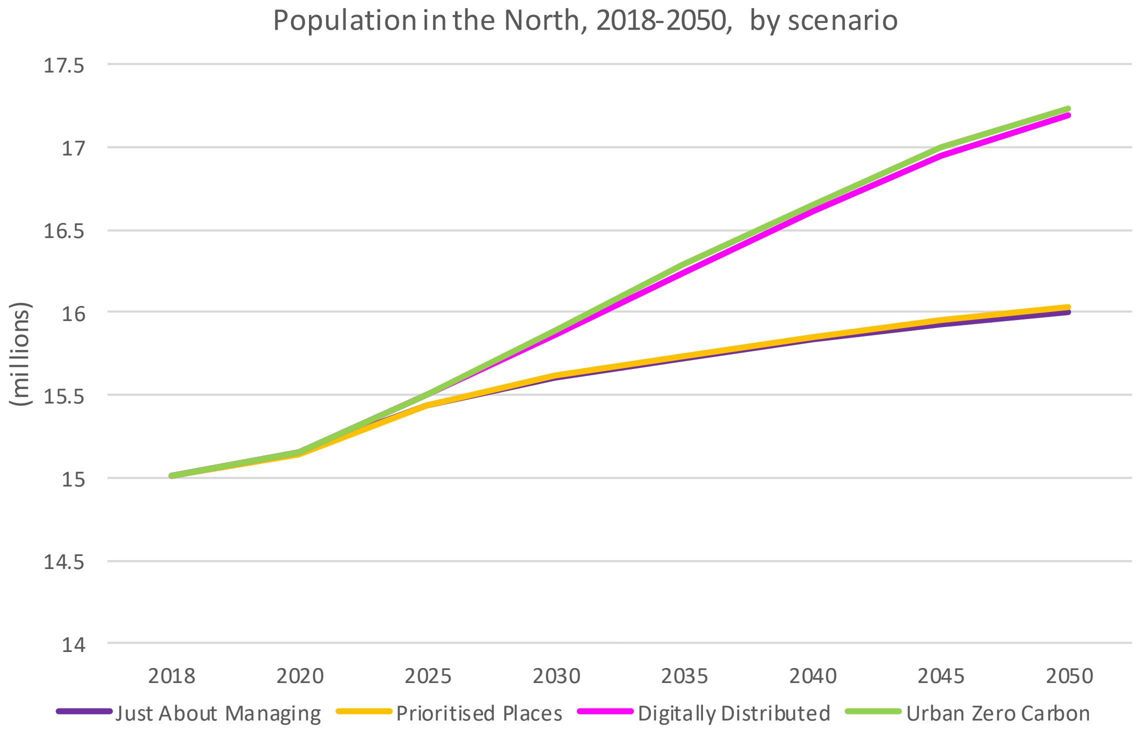

Figure 11. Modelled population in the North, 2018-2050.

Figure 12 shows the projections for jobs filled over the next 30 years in the North. The 'Business as Usual' scenarios reach about 7.3 million jobs in 2050, whereas in scenarios based on 'Transformational' growth, jobs reach 7.8 million in 2050.

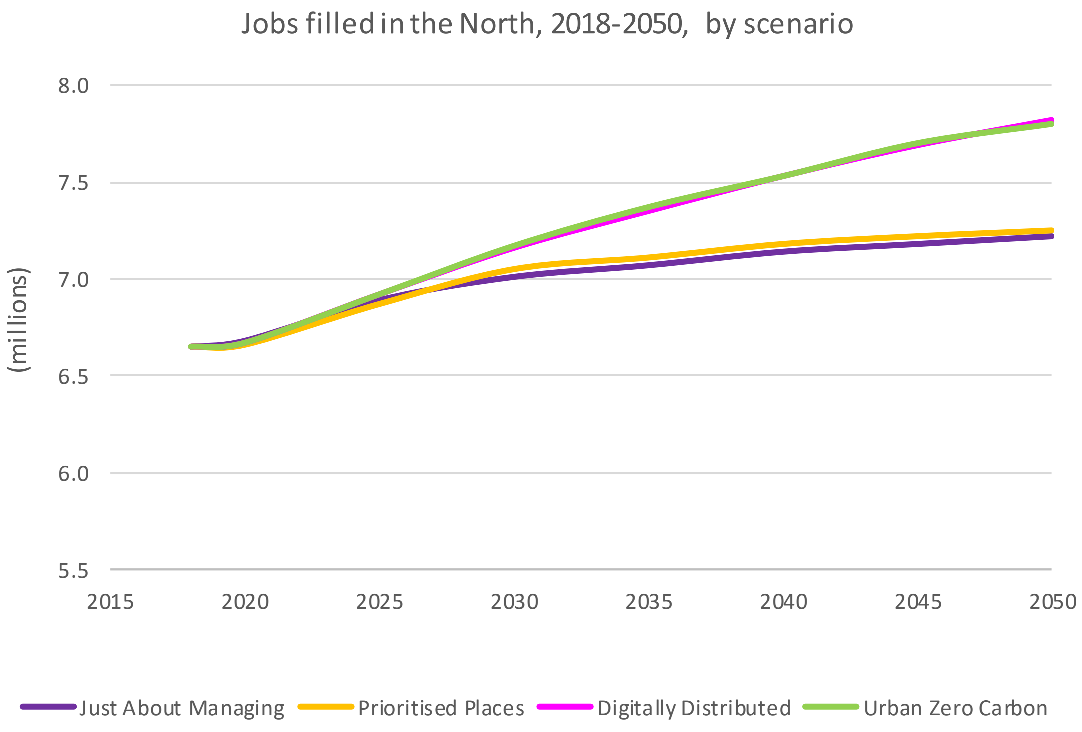

Figure 12. Modelled employment in the North, 2018-2050.

Population and job distribution

Population and jobs a key driver of transport demand, with localised population growth increasing pressure on local transport networks. The distribution of population and employment is therefore an important factor to consider in our scenario modelling. In Figures 11 and 12 the population can be seen reaching similar levels in 2050 for Just About Managing and Prioritised Places; and for Digitally Distributed and Urban Zero Carbon. The underlying distribution of population and employment in those two groups of the scenarios are however very different.

The distribution of population growth between 2018 and 2050 is presented across area types in the North in Figure 13. This corresponds to different distribution of growth in each scenario. Changes in population by zone are mapped in Figure 14.

- Just About Managing continues an existing trend towards more people living in urban and suburban areas with growth split between urban, sub-urban and rural area types at almost equal levels (ranging from 5% to 7%).
- Slower growth in cities and more growth in towns and rural areas (20%) is observed in in Prioritised Places in Figure 13.
- Digitally Distributed scenario sees the growth being dispersed across rural (17%) and sub-urban (16%) areas as the population distribution is less city-centric.
- Urban Zero Carbon scenario is the most compact scenario where most of the growth occurs in cities (33%).

A similar pattern is observed for Jobs filled between 2018 and 2050 in Figure 15.

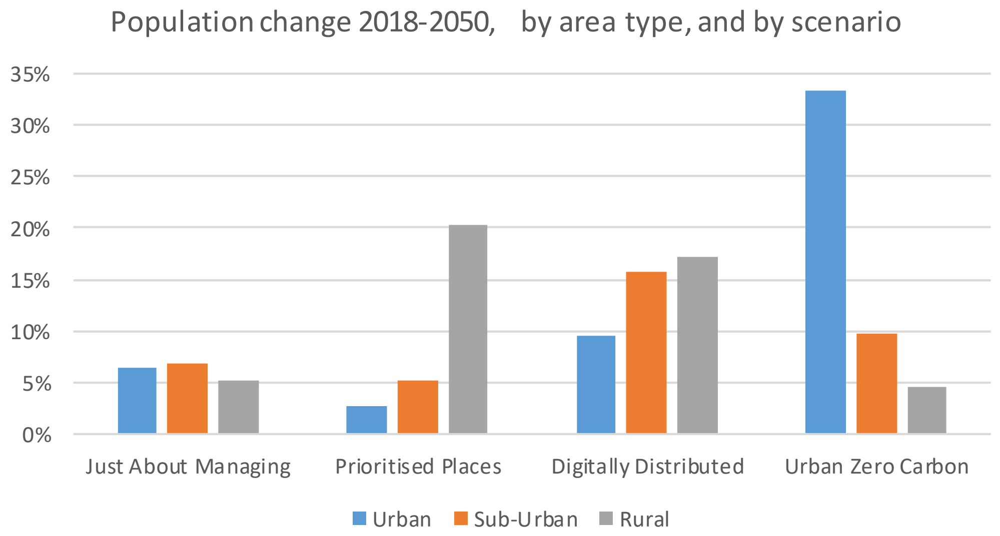

Figure 13. Distribution of population growth by area type, 2018-2050.

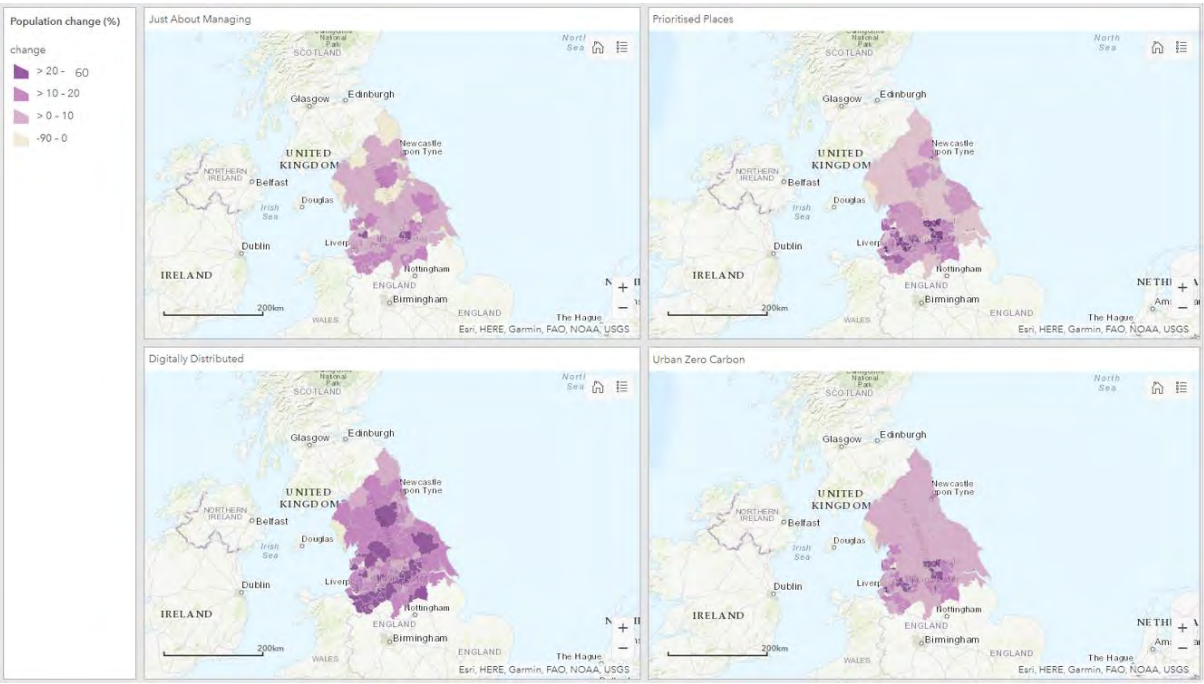

Figure 14. Distribution of population change, 2018-2050.

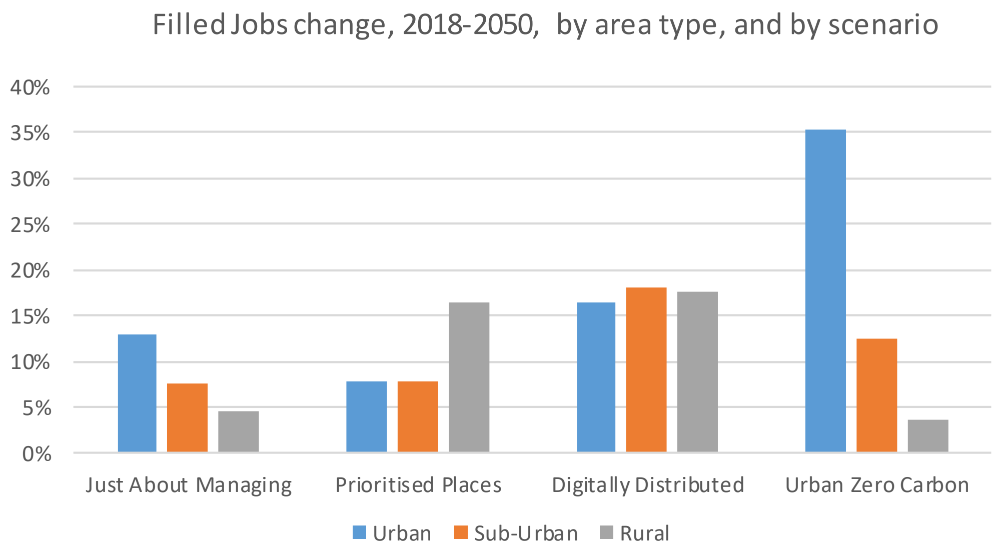

Figure 15. Distribution of employment growth 2018-2050, by area type.

6.2 Travel Demand

Travel demand is a key NELUM output, reporting person-trips between each zone pair. Those are recorded by four separate modes - car, rail, active modes and bus (including shared mobility) – and across different purposes – commute, business and other.

<u>Mode and purpose</u>

Demand across the transport network is expected to grow across all scenarios due to population increase, however the distribution of the demand growth across modes and purpose varies between scenarios (Figure 16). Travel behaviours are also strongly shaped by the built environment, directly influencing a person's decision to travel by a specific mode or route. The future transport challenges vary with geography and those are described below categorised by area type for each of the scenarios (Figure 17).

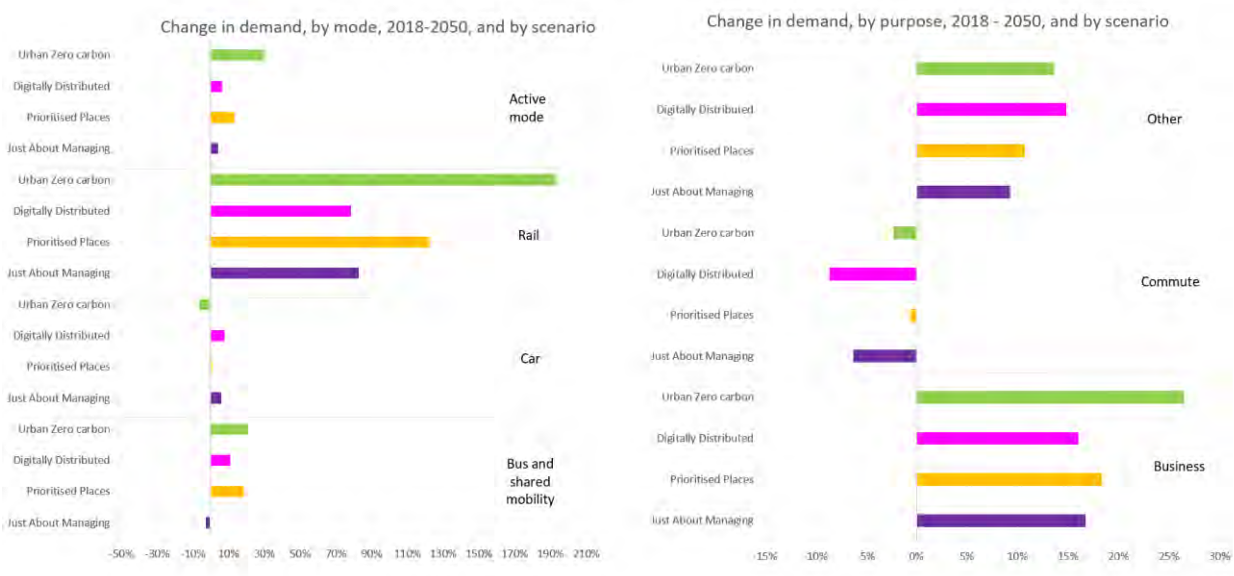

Figure 16. Change in demand by mode and purpose, between 2018 to 2050 and by scenario.

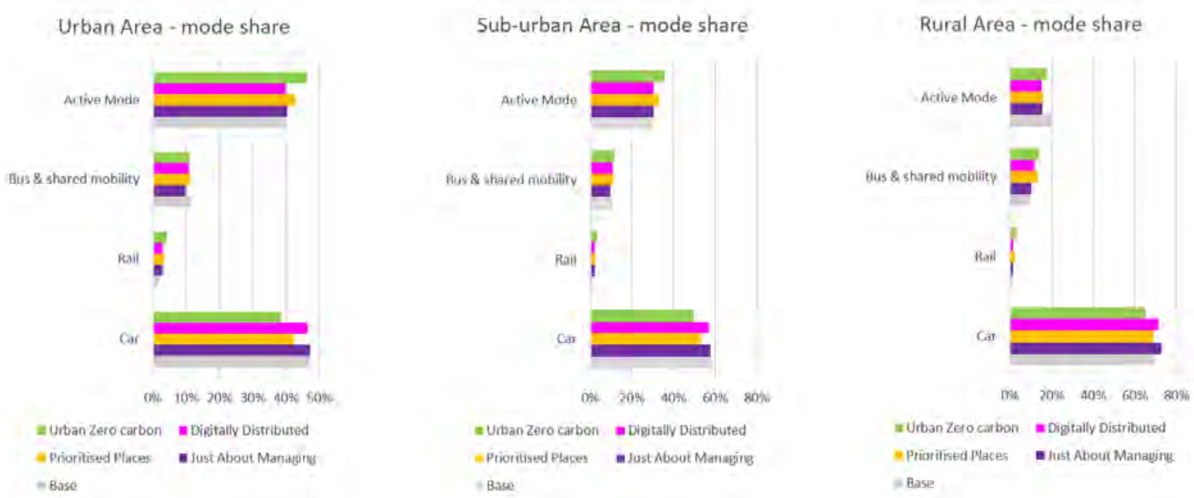

Figure 17. Mode share in 2050 across area types compared to 2018 (referred to as Base above).

Active modes

Travel by active modes increases across all scenarios, ranging from as little as 4% in Just About Managing scenario where there're minimal improvements to micro-mobility introduced, to the biggest change of 30% observed in Urban Zero Carbon scenario (Figure 16). Although 30% might seem like a relatively low increase compared to some local and national ambitions for increases in cycling, it is important to note that most active mode trips are walk trips, which already have a significant mode share. A 30% increase in active mode trips could be made up of a very significant increase in cycle trips (hundreds of percentage points increase) and a smaller increase in walk trips (tens of percentage points increase).

The highly urbanised distribution of growth in jobs and households in Urban Zero Carbon directly affects the distance people need to travel to work. This paired with improvements in infrastructure suited for micro-mobility and its high uptake, means that the active travel is chosen more often for short distance journeys. This is observed mostly in urban areas, where active mode increases as a mode share by 7pp there and by 6pp in sub-urban areas (Figure 17).

Prioritised Places sees an increase in active mode too, most probably due to more localised employment. This change is observed mostly in urban and suburban areas (Figure 17).

<u>Rail</u>

All scenarios see rail trips increase significantly between 2018 and 2050 ranging from 78% to 193%, however this increase should be considered alongside the very low mode share, which is presented in Figure 16. The increase in trips observed is mainly associated with GJTs improvements due to data accessibility and smart ticketing (as described in section 4) as well as other improvements on individual scenario basis. The increases do not however translate to a much higher mode share in any of the scenarios (Figure 16), the highest still being <4%.

Urban Zero Carbon which has the highest increase in rail trips, seeing a 2pp increase from base 2018 mode share in urban and sub-urban areas (Figure 17). This is mainly due to the focus on more sustainable modes through improvements in sustainable transport access and access to rail stations as well as public transport fare subsidisation and road user costs, all of which encourage people to choose more sustainable options of travel.

Prioritised Places sees the second biggest increase in rail trips in the North in 2050 due to improvements in sustainable public transport access and access to rail stations (Figure 16).

There are limited incentives towards sustainable modes in Just About Managing and Digitally Distributed scenarios and both see limited incentives to cars.

<u>Bus and shared mobility</u>

Bus and shared mobility trips increase for all scenarios except for Just About Managing (Figure 16).

In Prioritised Places and Urban Zero Carbon there is more support for traditional public transport schemes through sustainable transport access, and better access to rail stations as well as public transport fare subsidisation schemes.

Digitally Distributed scenario the increase is attributed to the new shared private mobility becoming more available (Figure 16).

Cars

Car journeys increase most notably in Just About Managing and Digitally Distributed (Figure 16). In both scenarios, there are limited incentives introduced towards sustainable modes.

As a result, Just About Managing sees a 6pp increase in car trips across all area types, causing a slight modal shift to even more car heavy future. Digitally Distributed shows an even higher increase in car trips, at 8pp mainly associated with higher population demand due to NPIER Transformational projections, and growth in employment and households being more dispersed across rural and sub-urban areas. This shift to a more suburban and rural growth has an impact on the distance people would need to travel to work and as public transport is often limited in those areas, people are more likely to depend on cars.

Road user costs are introduced in Digitally Distributed, which does limit growth, but that is not coupled with enough sustainable travel options and incentives to encourage people switch to alternative options. There is also a considerable uptake in Connected Autonomous Vehicles which contribute to demand on roads. Overall, this results in Digitally Distributed future of car demand being not much different to the car mode share of 2018.

Prioritised Places and Urban Zero Carbon have more support for active modes and public transport, leading to a plateau and a reduction in car trips, respectively. Figure 17 shows that the car decrease from 2018 for both scenarios across each of the area types.

Total vehicle kilometres

Figure 18 shows total vehicle-kilometres for all four scenarios, including car, van and HGV. Increases in distance travelled are partly driven by increases in trip length, as illusrated by the switch from intra to inter-district travel in Figure 19.

The increase is lowest in Urban Zero Carbon and highest in Digitally Distributed, as these scenarios have the most and least most car-friendly policies and change drivers respectively.

Prioritised Places also shows an increase above Just About Managing, largely due to more of the population living in rural locations where there is a need to travel further to reach destinations.

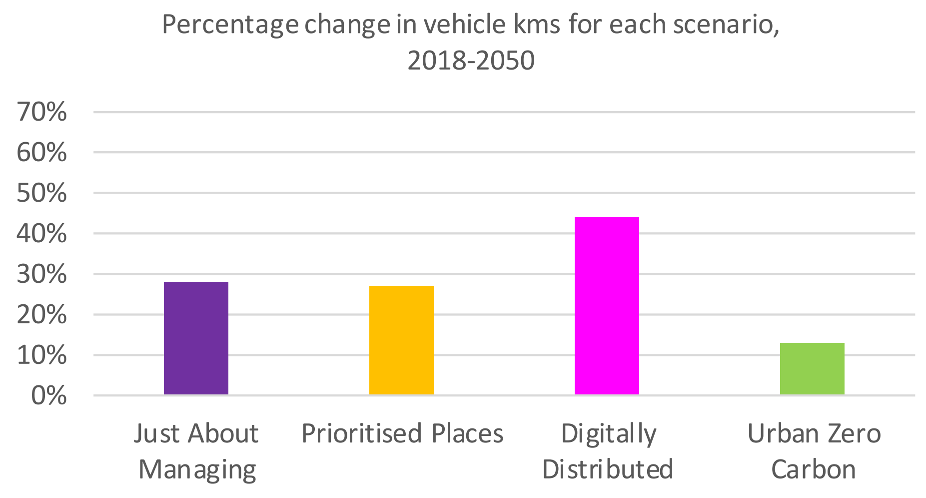

Figure 13. Change in vehicle kms for each scenario, 2018-2050. Includes cars, vans and HGVs.

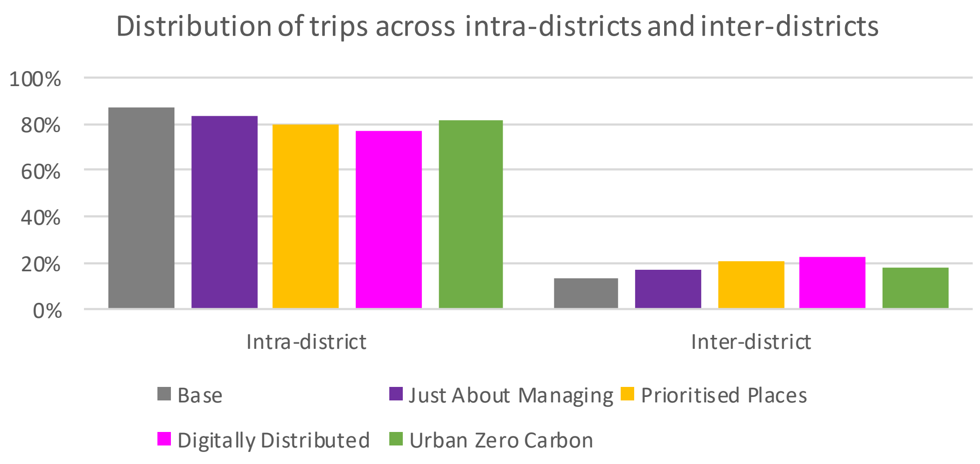

Figure 14. Distribution of trips across intra and inter-districts

Carbon Emissions

Figure 20 shows the total carbon emissions from the North's transport network by scenario between 2018 and 2050. Emissions decrease most in Urban Zero Carbon as lower car demand is combined with high uptake of zero emission vehicles. Urban and suburban areas benefit from people increasingly choosing to travel by more sustainable modes (Figure 21).

Digitally Distributed combines higher car demand with high zero emission vehicles uptake, meaning emissions are higher in shorter term.

Prioritised Places and Just About Managing have some zero emission vehicles uptake but not as high as other scenarios and this is reflected in their higher emissions (Figure 20), meaning they don't meet the carbon zero target in 2050.

Decarbonising freight also has a big impact on the total emissions as observed in Figure 22 in Digitally Distributed and Urban Zero Carbon scenarios.

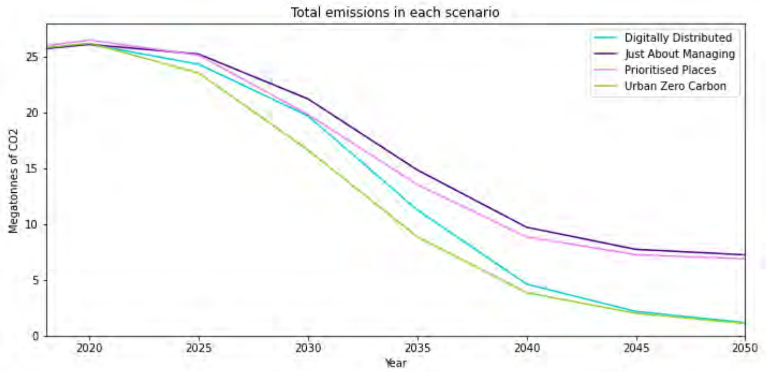

Figure 20. Total emissions in mega tonnes of CO_2 by scenario

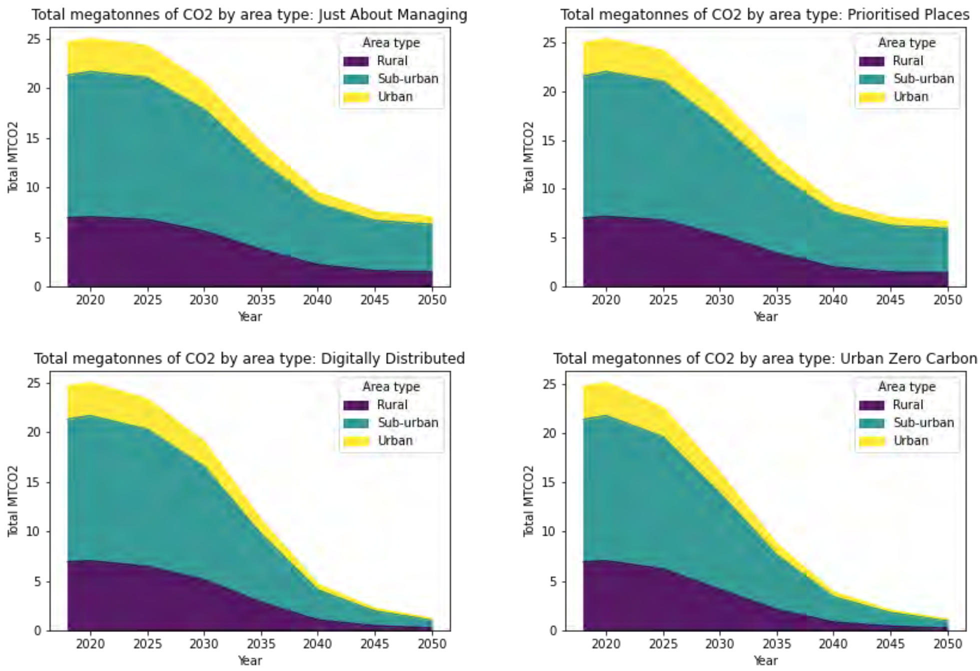

Figure 21. Total emissions by area type and scenario

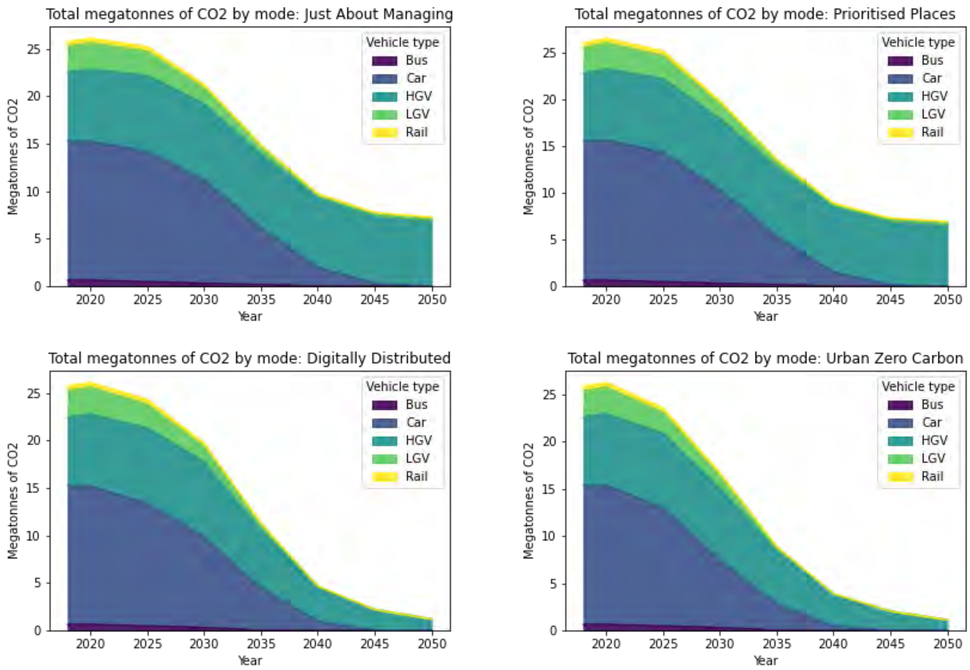

Figure 22. Total emissions by mode and scenario

7 Interactive visualisation dashboard

In order to make the Future Travel Scenarios transparent to the public, allowing them to explore the localised effects of the modelled results, we have created the Future Travel Scenarios Dashboard, accessible here.

This tool aims to provide the reader with a brief introduction to the TfN's Scenarios, the methodology used and presents the modelling results in an interactive way. The tool's goal is to tell the story of this project, and importantly how we're going to use the work in the future.

Figure 23. Illustration of NELUM data structure model

Data used within the dashboard comes directly from NELUM. The outputs include future population, jobs filled, GVA, and demand in terms of trips per person over time. Figure 23 summarises the data structure of the NELUM model outputs.

The Future Travel Scenario dashboard is divided into 3 main sections accessible as tabs titled: Introduction to TfN's Future Travel Scenarios, Scenario Results and What's next.

Each section is scrollable and interactive. The contact details are listed on the bottom of the page for any reader feedback. All the work on the dashboard has been iterative to date and easily editable so the feedback is valuable and can be incorporated into the tool development.

Introduction to TfN's Future Travel Scenarios

Introduction tab (Figure 24) provides a short description of the work, with descriptions of the four Future Travel Scenarios as well as a very short summary of the modelling and modelling inputs with links to the full reports available for more explanations.

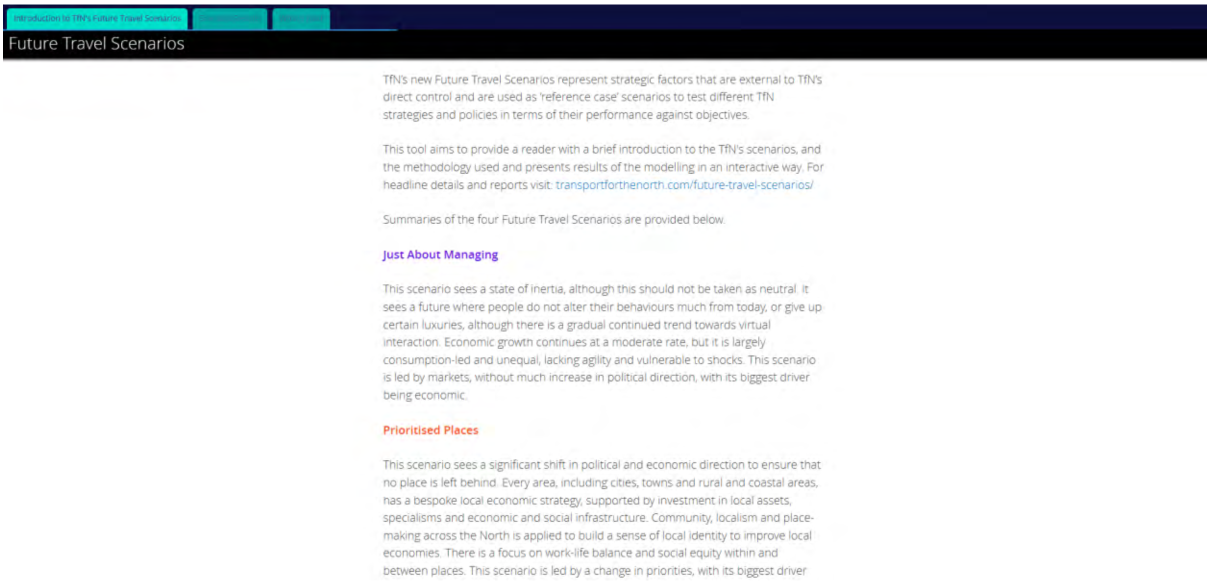

Figure 24. Screenshot of the Future Travel Scenarios tool – Introduction tab

Scenario Results

This section provides an overview of the socio-economic and travel implications of TfN's Future Travel Scenarios. All graphs, maps and figures are based on NELUM model outputs (Figure 23).

The initial screen (Figure 25) presents the high-level scenario comparison figures for each scenario in 2050 compared to 2018 Base scenario in terms of:

- growth in the population and the economy;
- spatial planning policy and economic distribution;
- technological advancement and uptake;
- social and behavioural change; and
- national environment and sustainability policy.

Figure 25. Screenshot of the Future Travel Scenarios tool - Scenario Results tab

The reader can explore the different scenarios by clicking on the headlines listed within the text.

The reader is then presented with a choice of either scrolling through or clicking on the headlines to explore the results in more detail.

Socio-economic results section include population, jobs and GVA and start with high-level projection trends shown for each of the scenario. As the reader scrolls down, the population and employment distribution are shown, letting the reader explore the map with local detail of the results that the Future Travel Scenarios work has captured. Those are presented using NELUM zoning system. When clicked on the zone, the pop-up window should illustrate the modelled change in the area (between 2018 and 2050) and a bar chart (Figure 26). For population, the bar chart presents the number of households by socio-economic structure (NS-SEC groupings) and for employment, it's the jobs filled by person type (based on SOC groupings). The dashboard also includes an explanation of the NS-SEC and SOC groupings used.

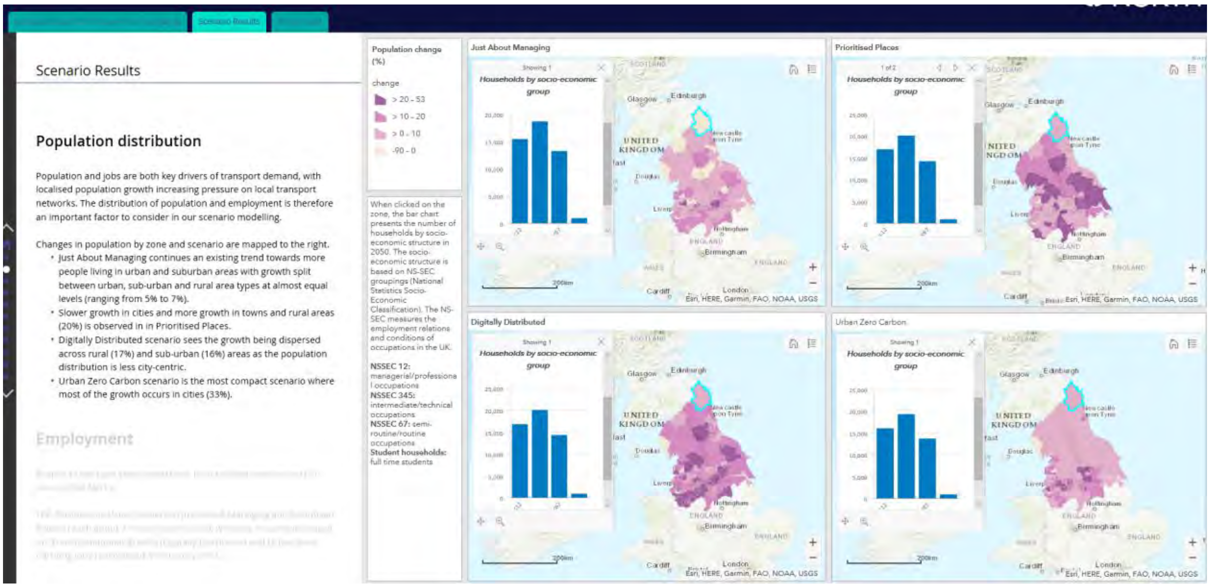

Figure 26. Screenshot of the Future Travel Scenarios tool – Scenario Results tab, Population distribution

The transport results section is split into trips by mode, change in trips by origin zone, mode share in 2050, trips by purpose. This section includes a set of interactive graphs and maps for change in trips by origin mode. The interactive mapping used for change in trips between 2018 and 2050 allow the reader to explore the change by mode for each zone selected. This is presented as a bar chart in a pop-up window.

The carbon emissions section summarises the results of the modelling for vehicle kilometres, including car, van and HGV as well as the change in distance travelled illustrated by distribution of trips across intra and inter-districts. The final screen shows the total carbon emissions for each scenario and then by area type.

What's next

This section includes a summary text on how the Future Travel Scenario results will be used in the future to test and refine the TfN transport strategies, policies and programmes.

8 Next steps

This section outlines work currently underway to represent the Future Travel Scenarios in other parts of TfN's Analytical Framework:

- The Northern Transport Modelling System (NorTMS)
- The Great Britain Freight Model (GBFM)

8.1 Representation of the scenarios in NorTMS

NELUM is a Land-Use Transport Interaction (LUTI) model with its own internal transport model. It is well suited to developing scenarios and modelling Wider Economic Impacts, but it is not suitable for detailed, conventional transport modelling and appraisal. For this reason, TfN is also developing representations of the same Future Travel Scenarios in NorTMS, the detailed, conventional transport modelling system.

TfN recognises that representing the same scenarios in two different modelling frameworks could lead to confusion over which system provides the 'right' output in each case. We propose to address this by making clear that the models are seeking to quantify different effects and explore two different but interacting types of uncertainty. NorTMS is intended to capture direct impacts for transport users and indirect environmental impacts from vehicles. NELUM's main focus is on Wider Economic Impacts and effects associated with land-use change. These different effects are presented separately ('Level 1-3' impacts) to emphasise the fact that there are different levels of uncertainty in their estimates. However, this uncertainty is associated with the endogenous impacts of transport accessibility changes, which is entirely separate from the exogenous uncertainty represented by the Future Travel Scenarios. It is therefore important to represent each scenario separately in both models to understand how the endogenous and exogenous uncertainties interact.

Although it is important to acknowledge that the different modelling frameworks use different analytical approaches and will produce different results, we are working to ensure alignment between the two tiers to help minimise any differences and achieve a reasonable degree of consistency. As noted above, this alignment is a key objective of the Northern Model Integration Tools (NorMITs).

Work is currently underway to represent the Future Travel Scenarios in NorTMS and is expected to be finalised in early 2021, for application in TfN programmes such as Northern Powerhouse Rail (NPR) and the Investment Programme (see the full Future Travel Scenarios report for more information on application in TfN programmes).

8.2 Representation in the GBFM

As noted above, a relatively simplistic approach to representing freight demand in the Future Travel Scenarios has been used for this report. We our currently working with our freight modelling partner, MDS Transmodal, to produce a more bottom-up representation of freight demand across each of the four Future Travel Scenarios using the GBFM.

Table 24 below shows the narrative describing the assumed implications of each scenario for freight.

Scenario	Growth in pop, emp and GVA	Climate change policy	Warehousing	Technology
Just About Managing	BAU – concentrated in cities	Moderate uptake in zero-emission vehicles	Dispersed	Moderate uptake in CAVs
Prioritised Places	BAU – more evenly spread	Moderate uptake in zero-emission vehicles	Compact, low urban consolidation	Low uptake in CAVs
Digitally Distributed	NPIER – more evenly spread	High uptake in zero-emission vehicles	Dispersed	High uptake in CAVs
Urban Zero Carbon	NPIER – concentrated in cities	High uptake in zero-emission vehicles	Compact, high urban consolidation	Moderate uptake in CAVs

Table 26: TfN initial assessment of the Future Travel Scenarios narratives for freight.

We have also made an initial qualitative assessment of the likely outcomes for freight in each scenario, shown in Table 25.

Scenario	Level of freight demand overall	Road / rail balance	Freight emissions	Road freight travel times
Just About Managing	'Business as Usual'	Biased to road	Slow reduction initially and does not reach net zero	'Business as Usual'
Prioritised Places	'Business as Usual'	Biased to rail	Fast reduction initially but does not reach net zero	Slightly longer due to more dispersed population
Digitally Distributed	'Transformational'	Strongly biased to road	Slow reduction initially but does reach net zero	Shorter due to improved effective capacity from CAVs
Urban Zero Carbon	'Transformational'	Strongly biased to rail	Fast reduction initially and does reach net zero	Longer, due to need to consolidate and deliver into cities

Table 27: TfN initial assessment of the Future Travel Scenarios outcomes for freight.

As with NorTMS, work is currently underway to represent the Future Travel Scenarios in the GBFM and is expected to be finalised in early 2021, for application in TfN programmes.

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